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FHWA/IN/JHRP-84/15

## ENERGY CONSERVATION AND COST SAVINGS RELATED TO HIGHWAY ROUTINE MAINTENANCE: PAVEMENT MAINTENANCE COST ANALYSIS

Essam A. Sharaf

Kumares C. Sinha

PURDUE UNIVERSITY

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Interim Report

# ENERGY CONSERVATION AND COST SAVINGS RELATED TO HIGHWAY ROUTINE MAINTENANCE: PAVEMENT MAINTENANCE COST ANALYSIS

TO: Harold L. Michael, Director
Joint Highway Research Project

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

August 23, 1984

Project: C-36-67L

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Attached is the Interim Report on the HPR Part II Study entitled "Energy Conservation and Cost Savings Related to Highway Routine Maintenance." This interim report covers Task I of the extended work plan of the study dealing with routine maintenance requirements by type of pavement. The research was conducted by Essam A. Sharaf under my direction.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the research.

Respectfully submitted,

KCSinha

K. C. Sinha
Research Engineer

KCS/rrp

cc:
A. G. Altschaeffl
J. M. Bell
W. F. Chen
W. L. Dolch
R. L. Eskew
J. D. Fricker
J. R. Skinner
W. H. Goetz
G. K. Hallock
J. F. McLaughlin
R. D. Miles
P. L. Owens
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K. C. Sinha
C. A. Venable
L. E. Wood
S. E. Yoder

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Interim Report

# ENERGY CONSERVATION AND COST SAVINGS RELATED TO HIGHWAY ROUTINE MAINTENANCE: PAVEMENT MAINTENANCE COST ANALYSIS

Essam A. Sharaf
Post-Doctoral Research Fellow

and

Kumares C. Sinha
Professor of Civil Engineering

Joint Highway Research Project

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and the

U.S. Department of Transportation
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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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Essam A. Sharaf and K. C. Sinha

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This report presents the results of the research work relating routine maintenance costs with pavement charateristics. The report covers the following major items: (i) development of a comprehensive data base that combines pavement maintenance information, climatic zone, traffic information, and pavement characteristics; (ii) development of pavement maintenance rates by highway system, by pavement type, and by climatic zone; (iii) analysis of labor, material, and total expenditure trends over the last four fiscal years; (iv) correlation analysis between yearly total expenditures and that between shares of different activities of total expenditures; and (v) analysis of the relationship between the level of pavement routine maintenance and pavement characteristics.

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## EXECUTIVE SUMMARY

This interim report presents an analysis of pavement routine maintenance costs of the state highway system of Indiana. The phase of the study reported here included: (i) development of a comprehensive data base that combines pavement maintenance information, climatic zone, traffic information, and pavement characteristics; (ii) development of pavement maintenance rates by highway system, by pavement type, and by climatic zone; (iii) analysis of labor, material, and total expenditure trends over the last four fiscal years; (iv) correlation analysis between yearly total expenditures and that between shares of different activities of total expenditures; and (v) analysis of the relationship between the level of pavement routine maintenance and pavement characteristics. Multiple regression was used to develop prediction models for total maintenance expenditure as well as for level of expenditure in maintenance groups of sealing and patching activities. Possible applications of the study results are illustrated through examples involving tradeoff between patching and sealing as well as between routine maintenance and resurfacing.

# CHAPTER 1

# INTRODUCTION

## 1.1 General

Current highway maintenance programming processes are greatly influenced by three factors: (i) increasing rate of pavement deterioration since a large part of the existing system is rapidly aging; (ii) continuing inflation and cost increase of all highway resources; and (iii) uncertainty surrounding the level of available highway revenue for routine maintenance.

The overall impact of aging of the highway system can be best illustrated by the fact that in 1975 only 4 percent of the nationwide interstate system needed resurfacing, restoring, or rehabilitation, whereas about 10 percent of the interstate system needed these activities in 1978 (57).

At the same time the inflationary and price increasing pressures in recent years made it difficult to undertake such expensive major projects as resurfacing or rehabilitation. With the passing of the 1982 Surface Transportation Act providing additional 5 cents motor fuel tax, a substantial increase in Federal aid is expected and therefore many of and so far deferred major maintenance activities can now be considered. However, routine maintenance activities do not receive any Federal aid and they must be accomplished through the state generated revenues. Increased Federal aid also requires increased matching funds from the state sources, and thus if there are no additional state revenues, less funds for routine maintenance may be available. Consequently, routine maintenance is receiving a considerable attention from highway agencies at all levels of government.

## 1.2 Purpose of the Study

Pavement management, in its broadest sense, encompasses planning, design, construction, rehabilitation, and maintenance of the pavement portion of a public works program. A pavement management system (PMS) is a set of tools or methods that assist decision-makers in finding optimal strategies for providing and maintaining pavements in a serviceable condition over a given period of time. The function of a PMS is to improve the efficiency of decision-making, expand its scale, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and maintain the consistency of decisions taken at different management levels within the same organization (1).

A Maintenance Management System (MMS), as a part of the overall PMS, could be defined as a technique or operational methodology for managing, directing and controlling maintenance resources for optimal benefits (2). To operate successfully such a system, the following components should be available (1):

1. An inventory of the physical elements of the pavement system that can be maintained, plus the physical, operational, and environmental factors that can influence the amount of maintenance work generated.

2. Performance standards that define maintenance procedures, resources in terms of labor, equipment, and materials, and the average accomplishment production rate expected from following the standards.

3. Prediction of the work load generated in terms of maintenance accomplishment units, by a physical element of the highway pavement, that is, a pavement of a given design subjected to specific traffic loadings in a given environment.

4. Allocation of available resources through objective budgeting mechanisms based on the specific requirements of the pavement system and policy decisions related to the quality or level of maintenance desired.

5. Feedback reports to monitor and update the system.

An important purpose of the maintenance management component in a pavement management system is to monitor the costs associated with providing various levels of serviceability for any given pavement. This information is necessary as feedback to planning, design, and construction. The costs are dependent on the type and degree of maintenance which can in turn influence pavement performance in terms of the rate of serviceability loss for a pavement.

The success in achieving the objectives of a MMS depends primarily on the availability and accuracy of the necessary information for the five components mentioned above. The maintenance management section of the IDOH had the first component, inventory, available. The second component, a set of performance standards, was also found to be available; however, the equipment information, particularly in the area of fuel consumption, did not exist. Very little of the last three components were available.

The lack of necessary information for the components of an effective maintenance management system was the general motivation for this research study. The primary objectives of the research were 1) to complete the inventory data, 2) to update the performance standards and 3) to relate maintenance needs to physical and environmental characteristics of the pavement system. These objectives were motivated not only because the resulting information would help the maintenance managers in preparing the annual maintenance program, but also because such information is vital for an effective integration of the MMS within the PMS framework. A major element needed to achieve these objectives is to have reliable data for resource consumption in maintenance activities. Consequently, it was decided to divide the research study into three phases. The first phase was to complete the inventory and to update the current performance standards including new standards for fuel consumption. The results of this phase have been reported in an earlier interim report (4). The second phase was to develop statistical models to predict maintenance needs (costs) as function of pavement system characteristics. The present interim report provides the findings of the second phase. The third plan involves the development of optimal strategies for energy and cost savings in routine maintenance and it is currently underway.

## 1.3 Summary of Literature Review

### 1.3.1 Routine Maintenance and Pavement Management System

As the results of the AASHTO road test (12) became available, new approaches to pavement design and maintenance started to be developed. A systematic approach to the pavement design process led to the concept of pavement management system (13,14,15). Many studies were conducted in late 1960's and early 1970's in an attempt to formulate and define this new concept (16,17). An attempt to develop an actual working system for systems approach to pavement design was reported in References 18 and 19.

Pavement management, in its broadest sense, encompasses all activities involved in planning, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program. Although, pavement routine maintenance was emphasized in several studies (1,20,21,22,23) as a part of a PMS, it has not been effectively incorporated in pavement management system development. The reason for not explicitly considering routine maintenance may be the existence of an organizational structure where maintenance department is separated from other departments. Moreover, routine maintenance activities are funded entirely be the state, while funds for other activities such as construction, rehabilitation, resurfacing, and so on, are shared with the federal government. This situation has led to separation of maintenance decisions from decisions regarding other activities. This fact is evident in Reference 24 where the experience of several states in initiating PMS is explained. The basic concern of most of the pavement management systems is to develop a scheduling program for rehabilitation activities with minimal consideration of routine maintenance in the decision-making process. The main reason for this situation may be due to the fact that most of the states are in their beginning stages of developing PMS, and it is usually easy to begin with single management area, particularly involving rehabilitation, with additional areas to be added in later stages (20).

Although routine maintenance management has not yet been directly incorporated in pavement management systems, it is recognized that effective decisions regarding major maintenance activities cannot be made without appropriate consideration of routine maintenance. The present research is aimed at developing relevant information on routine maintenance that can be input to an integrated PMS.

In the following paragraphs, the literature in the area of the present research is briefly summarized under three broad categories:

1. Maintenance practices and standards;
2. Pavement distress and relation to pavement performance;
3. Maintenance needs (costs) and relation to pavement systems characteristics.

### 1.3.1.1 Maintenance Practices and Standards

In estimating maintenance needs (costs), one should be aware of the current practices and standards of maintenance operations. The change of the standards from place to place or from time to time may significantly affect the corresponding unit costs. Almost every state has its own manual for maintenance and these manuals generally give operational guidelines. For instance, Reference 25 is an example of such a manuals for the IDOH. However, there are technical guidelines involving maintenance activities (27,28,29,30, 31,32,33,34). These guidelines provide technical details where the pavement deficiencies are identified and suggested methods of repair are suggested.

### 1.3.1.2 Pavement Distress and Relation to Pavement Performance

There have been many studies to classify different types of pavement distresses, their causes, and possible repair or maintenance. A selected set of references in this topic includes References 29,35,36,37,38,39,40, and 41. The information on pavement distress along with the available maintenance practices are usually used in the process of predicting the cost of specific pavement deficiencies.

Studies on possible causes of pavement distress and method of repair (maintenance or rehabilitation) usually do not relate the type or severity of distress to the overall performance of the pavement system. However, such relationship is important in a PMS where the decision of type and quantity of repair depends on the effect of distress type and severity on pavement performance. The general approach to develop such relationship is to establish certain performance indicators (PI) each of which takes a maximum value for pavements with excellent condition, and a minimum value for pavements with poor condition. Usually a deduct value is used to reduce the maximum value of a PI based on type and severity of the distress. Critical distress types with high severity are assigned a high deduct value, while noncritical distresses with low severity are assigned a low deduct value.

Some of these studies are general and cover most of the distress types (47,43,44). Other studies are more specific involving particular types of distresses (45,46).

#### 1.3.1.3 Maintenance Needs and Relation to Pavement Systems Characteristics

Most of the studies of types discussed above assume that actual distress data are available to the engineer. This assumption restricts the use of these studies in long range pavement management decisions which require a recognition of future distress type and severity. For the purpose of long range pavement management planning it is necessary to predict pavement performance as a function of pavement system characteristics. Some of the early studies in this area took place after the AASHO road test (5,12). Since then, several studies had been conducted in this area (47,48,49). However, most of these studies did not define a methodology to use the performance values of a pavement system in predicting maintenance needs; the basic concern of these studies was to use pavement performance information in scheduling rehabilitation programs.

The need for methods or models to predict future maintenance needs (costs) is critical. The major difficulty in developing such models is that maintenance activities are are aimed at correcting a pavement distress as it occurs on a continuous basis rather than at specified periods of time as in periodic highway improvement activities.

Despite this difficulty, several studies attempted to provide ways to predict pavement routine maintenance needs. Generally, these studies can be divided into three major approaches. The first approach is based on monitoring a set of test sections. This approach has been used by several states; however, the most extensive use of this approach was made in Texas where several studies were conducted at the Texas A&M University (50,52,53,54,79). Full control over test sections allows the development of sophisticated models that can consider temperature, type of mixtures and so on, beside the usual factors such as age and traffic.

The second approach uses the available pavement evaluation information, such as riding quality and pavement cracks, along with the maintenance records to develop prediction models of pavement routine maintenance needs. Models of this type were developed in Arizona in connection with the comprehensive pavement management system (69). The survey study presented in Reference 78 also indicated such use.

The third approach is to use directly the available routine maintenance expenditure data that are collected on a regular basis along with information on pavement system characteristics (type, age, traffic level, percent of trucks) to develop such models. This approach has been used in several studies (70,71,76,77). However, some of these studies were limited to a specific highway type or a particular pavement type. Basically, two types of statistical models were used; multiple regression and time series analysis (71). The problem of a time series analysis is the need for historical data extended over a period of years and such data are not available in most states, particularly in Indiana where information for only four years is available.

In summary, a review of literature indicated the use of several methods in pavement routine maintenance prediction. Some of these models are very detailed and the adoption of the procedure requires continuous condition survey which in turn requires substantial resources. On the other hand, methods or models that utilize the available data are very simple considering either only pavement age (76) or only pavement type (84) to develop maintenance rates without including other factors that may significantly affect maintenance needs. Then again there are other models that require a considerable amount of historical data which are not usually available at the state level and can only be applied to systems where detailed past records are kept, as in the case of turnpike study in Reference 71.

There is, therefore, a definite need for models that can be directly developed utilizing the available statewide data, but accurate enough to reflect different characteristics of the state highway network such as highway type, pavement type, traffic level, climatic zones and so on. The present study is perhaps the first attempt to make use of the already available data in a comprehensive routine maintenance cost analysis covering an entire state highway network. This study not only included physical characteristics of the state highway system, but also indirectly considered the administrative characteristics and policies related to routine maintenance.

## 1.4 Report Organization

The research reported here relates maintenance needs to pavement characteristics. In Chapter 2 the development of the data base is presented. Chapter 3 includes the trends of different resource uses over the last four fiscal years (1980-1983). A disaggregate analysis of routine maintenance rates for different pavement types and climatic zones of Indiana is then presented in Chapter 4. Chapter 5 is devoted to a Pearson correlation analysis involving both total maintenance expenditure and expenditures in individual activities. Chapter 6 discusses a set of statistical models for the prediction of pavement routine maintenance cost distribution of total cost among major activity groups, patching and sealing. Chapter 7 presents two applications of the statistical models concerning energy savings in routine maintenance and tradeoff between resurfacing and routine maintenance. This phase of the study is concluded with a summary of major findings in Chapter 8.

# CHAPTER 2

# DEVELOPMENT OF PAVEMENT MAINTENANCE DATA BASE

## 2.1 Introduction

A data base is a key element in any Pavement Maintenance Management System (PMMS). The overall effectiveness of a pavement management system is dependent on the accuracy and reliability of the data base. One of the major problems faced in this research was the lack of a consistent data base that includes all relevant information required for the analysis of the existing system or to be used in the development of maintenance cost prediction models. Moreover, the existing data files were found to have been recorded in terms of different management units. For example, while the highway inventory files take the highway contract as the base unit for recording system, routine maintenance information is stored by subdistrict (a subdistrict may include many contracts).

The first task was to choose the management unit or the base unit that conforms with various data sources. The subdistrict was found to be a very highly aggregated level and a considerable amount of information could be statistically lost if it was considered as the base unit. On the other hand, while the contract is the most desirable unit, the maintenance records could not be broken down by contract. Therefore, a highway section was found to be the most appropriate unit for the existing data system and for the purpose of this research. A highway section is defined as the portion of a specific highway that lies between county limits.

The entire highway system was divided into 874 highway sections. Each section is defined by:

a. Section Number;

b. Highway System

   Interstate System (IS)

   Other State Highway System (OSHS)

c. Highway Number;

d. County Number;

e. District Number; and

f. Total Lane Miles.

For each highway section, four major groups of information were summarized: traffic, pavement characteristics, climatic zone, and pavement maintenance records. Traffic information includes average annual daily traffic (AADT), percent of trucks, and finally the equivalent axle load (EAL) which is used as a common traffic index that accounts for different vehicle types and weights. Pavement characteristics include pavement type, layer thickness(es), and age. Climatic zones are those geographical areas with similar climate in terms of snowfall, rainfall, temperature difference and so on. Finally, pavement maintenance records include total production units, total man-hours, and types and quantities of materials. Pavement maintenance information is summarized for each section by activity by fiscal year.

Each of the above information groups is discussed in more detail in the following sections.

## 2.2 Average Daily Traffic

Average daily traffic used here is the average annual daily traffic values adjusted for seasonal variation. The basic source for ADT information used to develop the data base was the traffic counts and studies performed by the Planning Division of the IDOH. However, the availability, suitability, and accuracy of such information were not in complete agreement with the level required by this research. A major problem was the incomplete ADT records for the base year (1981-1982). To overcome this problem several steps were taken, as discussed below.

The first step was to summarize and code the available ADT information. At the time of conducting this phase of the research, only 48 counties out of the 92 counties in Indiana were found to have complete traffic maps for 1981-82. Figure 2.1 is an illustration of such traffic maps and Figure 2.2 shows counties with available traffic maps at the time of this research. Each highway section was divided into one or more segments. These segments were determined on a basis of noticeable variation in the ADT value. To explain, a new segment was considered if its ADT value was ± 10% or more of the adjacent segment's ADT value. ADT values for different segments were coded along with

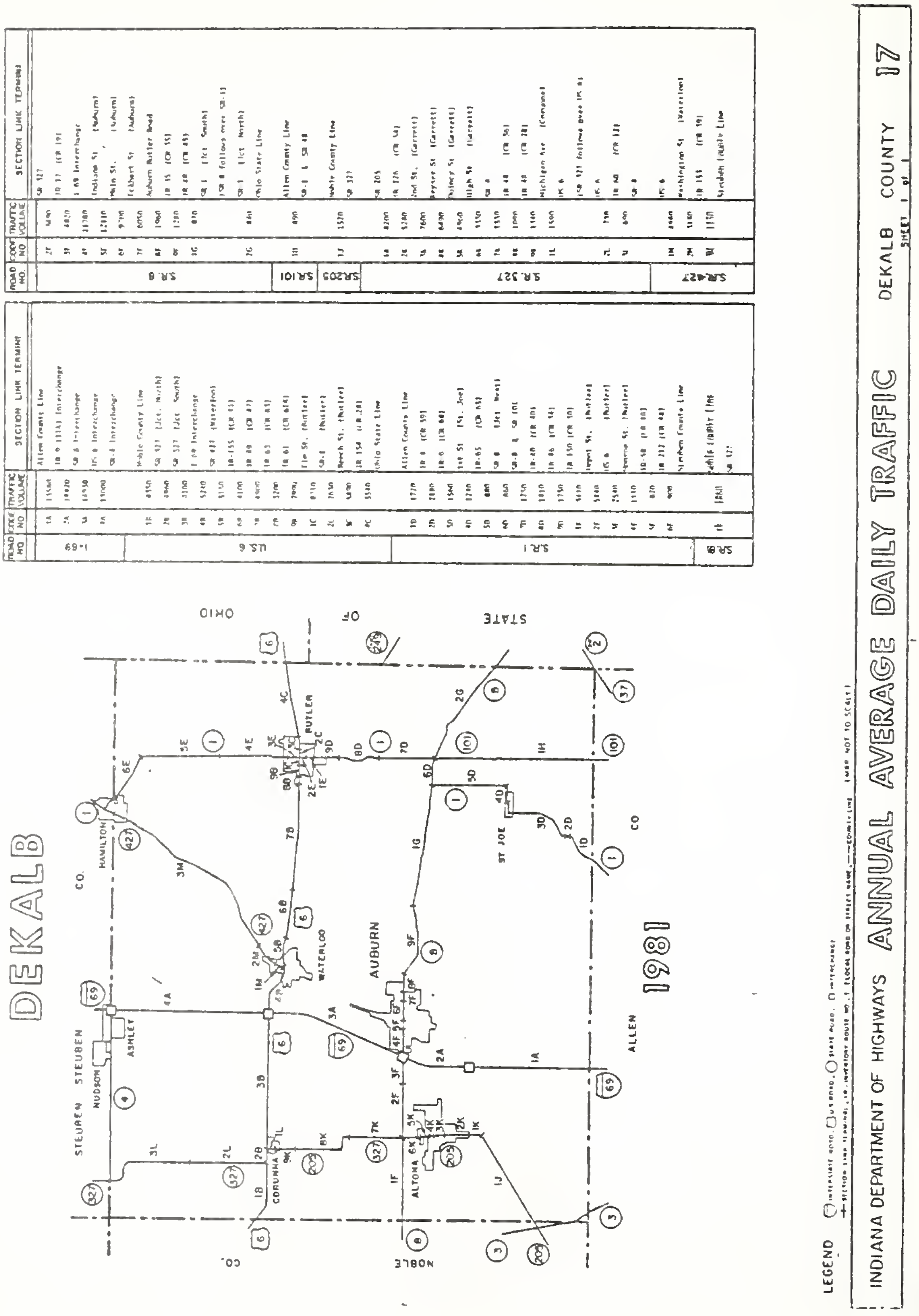

Figure 2.1 Example of Traffic Maps

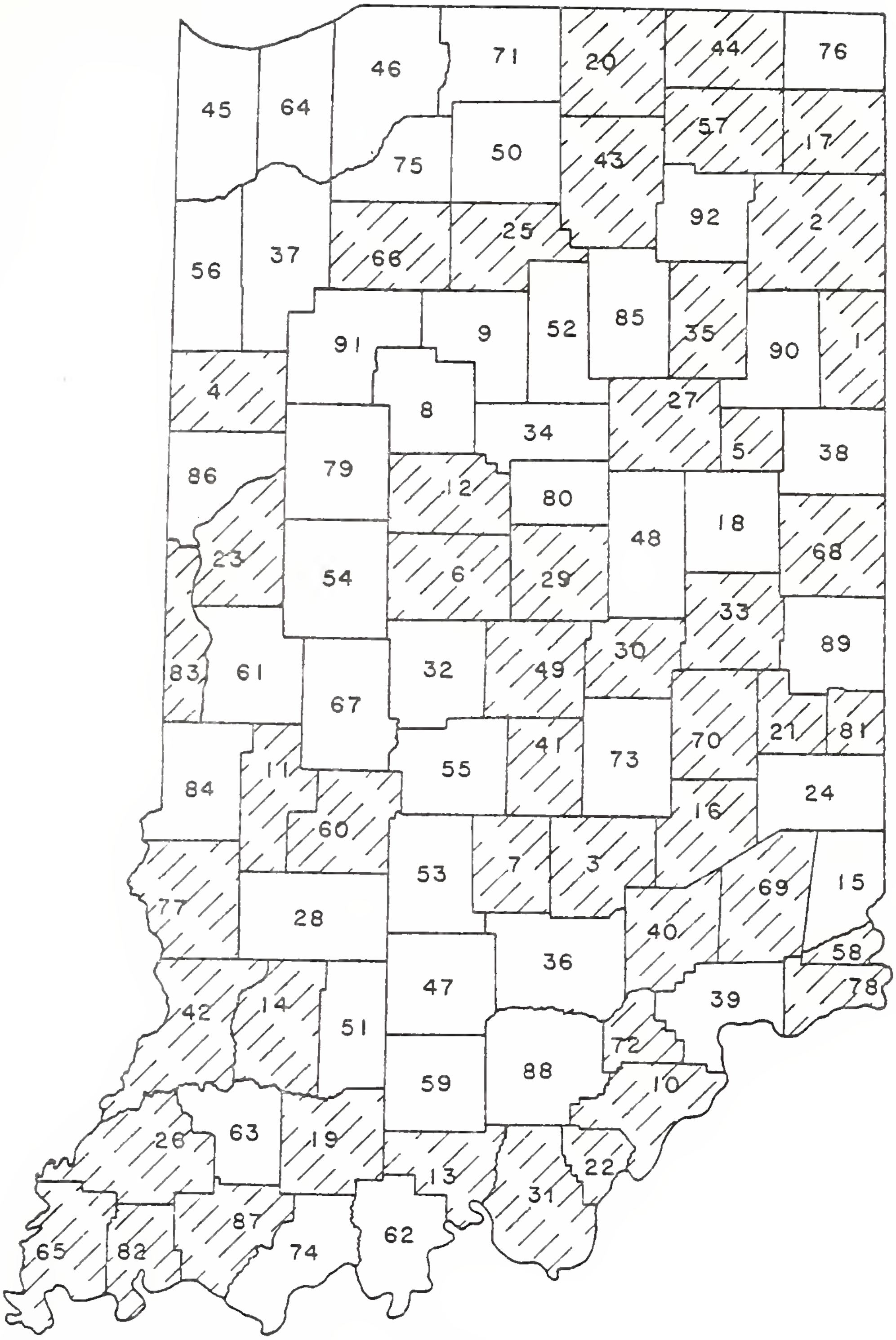

Figure 2.2 Counties with Complete Traffic Maps.

their corresponding lengths. Also, a weighted average ADT value was calculated for each highway section within a county using equation 2.1.

$$AVADT = \frac{\Sigma\ ADT_i * L_i}{\Sigma\ L_i} \tag{2.1}$$

where,

AVADT = average ADT value for a highway section;

$ADT_i$ = ADT value of the $i^{th}$ segment within the highway section;

$L_i$ = length of the $i^{th}$ segment within the highway section.

The above procedure was applied for all sections in the counties with updated traffic maps. Knowing the 1981-82 updated value of ADT for each highway section on those counties along with the old ADT values (1978 update), a factor was developed for each of these sections indicating the ratio between the 1981-82 ADT value and that of 1978. For example, a section with ADT value of 11000 vpd in 1981-82 update and 10000 vpd in 1978 will have an updating factor of 1.10 or the ADT of this section was subjected to a growth of +10% during the period, 1978 to 1982.

In the second step, sections without updated traffic counts for 1981-82 were considered. Each of these sections was assigned a traffic growth factor similar to another section with known 1981-82 ADT value. For example, in Figure 2.3 section \`a´ lies within County \`A´. This section has 1981-82 ADT value of 11000

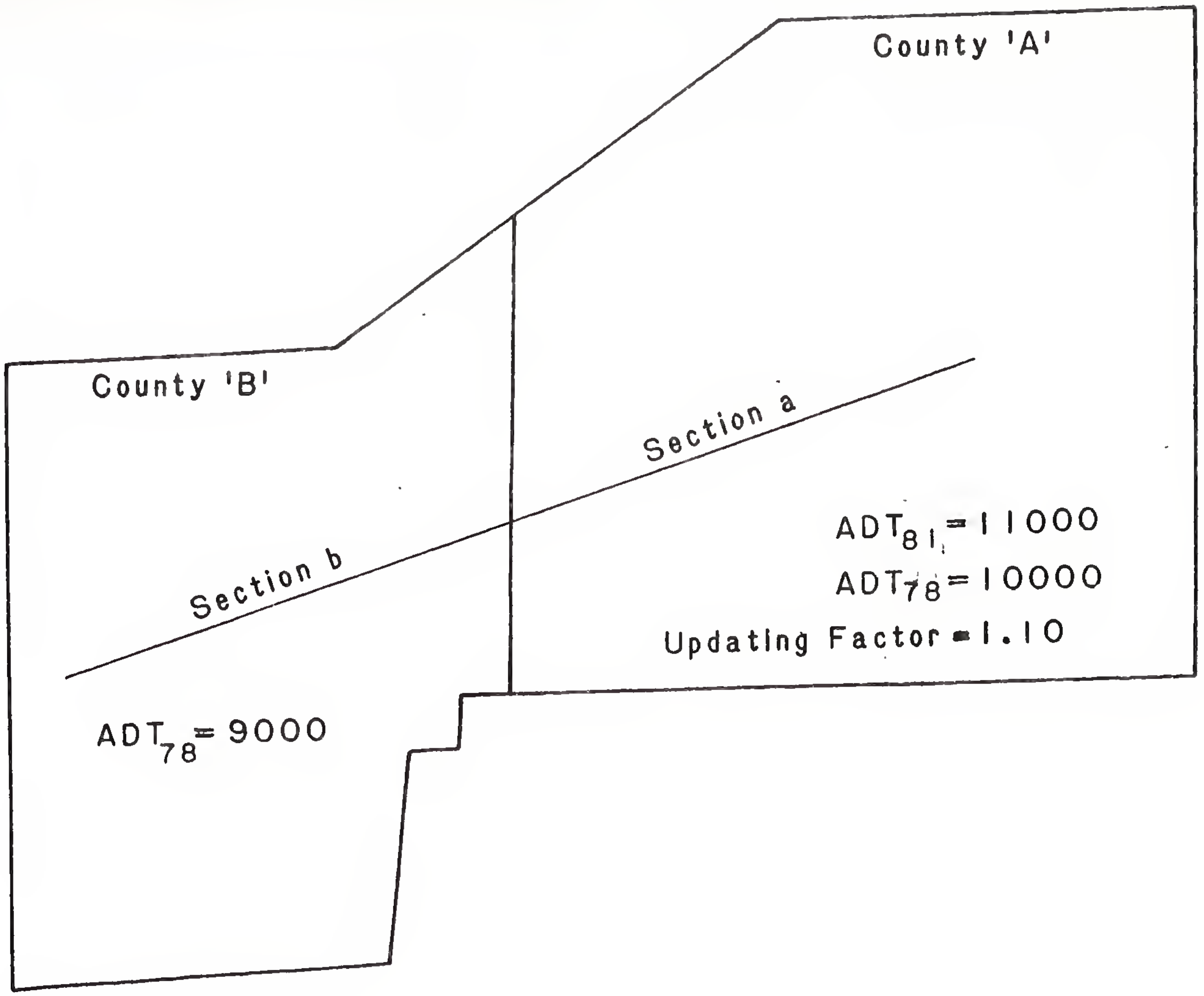

Figure 2.3 . Illustration of the ADT Updating Procedure.

and 1978 ADT value of 10000, with an updating factor of 1.10. Section `b´ is an extension of the same highway but lies within County `B´. Only the 1978 ADT value of 9000 is known for section `b´. In this case, the updating factor of section `a´ is used to obtain the 1981-82 ADT value of 9900 vpd (9000 * 1.10). This process was used for all sections in the counties without 1981-82 updated traffic maps. This way all highway sections representing the Indiana State Highway system were assigned ADT values for both 1978 and 1981-82.

For the period proceeding 1978, the 20-year growth rates developed by the IDOH Planning Division for each county were found to be adequate for generating appropriate ADT values. These rates were developed based on actual traffic counts of the state roads for the period of 1955-1975. Different growth factors for rural and urban areas within each county were also included. Table 2.1 lists these factors for different counties. Since factors were not broken down by highway sections within each county, it was assumed that the overall growth rate of a county would apply for all highway sections within that county. These growth rates along with those developed for the period of 1978-1982 cover the age range of most of the existing highway sections. For sections with age counted from a year before 1955, the 20-year growth rates were simply extended.

At this point, the knowledge of 1978 ADT value was enough to estimate the ADT value for any other year using appropriate growth rates described above. Another factor was then introduced

Table 2.1 Twenty-Year ADT Growth Factors

| 20 YEAR FACTOR | | URBAN | | RURAL | | 20 YEAR FACTOR | | URBAN | | RURAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Adams | 1.535 | | 1.337 | | 47 | Lawrence | 1.460 | | 1.383 | |
| 2 | Allen | 1.662 | | 1.494 | | 48 | Madison | 1.625 | | 1.416 | |
| 3 | Bartholomew | 1.741 | | 1.722 | | 49 | Marion | 1.755 | | -- | |
| 4 | Benton | 1.401 | | 1.252 | | 50 | Marshall | 1.484 | | 1.397 | |
| 5 | Blackford | 1.426 | | 1.342 | | 51 | Martin | 1.533 | | 1.260 | |
| 6 | Boone | 1.522 | | 1.439 | | 52 | Miami | 1.594 | | 1.487 | |
| 7 | Brown | -- | | 1.702 | | 53 | Monroe | 1.837 | | 1.792 | |
| 8 | Carroll | 1.363 | | 1.302 | | 54 | Montgomery | 1.412 | | 1.365 | |
| 9 | Cass | 1.319 | | 1.302 | | 55 | Morgan | 1.750 | | 1.655 | |
| 10 | Clark | 1.740 | | 1.659 | | 56 | Newton | -- | | 1.323 | |
| 11 | Clay | 1.334 | | 1.261 | | 57 | Noble | 1.607 | | 1.401 | |
| 12 | Clinton | 1.441 | | 1.199 | | 58 | Ohio | -- | | 1.308 | |
| 13 | Crawford | -- | | 1.189 | | 59 | Orange | 1.419 | | 1.255 | |
| 14 | Daviess | 1.360 | | 1.258 | | 60 | Owen | -- | | 1.353 | |
| 15 | Dearborn | 1.483 | | 1.314 | | 61 | Parke | 1.461 | | 1.188 | |
| 16 | Decatur | 1.570 | | 1.463 | | 62 | Perry | 1.524 | | 1.333 | |
| 17 | Dekalb | 1.455 | | 1.369 | | 63 | Pike | 1.281 | | 1.172 | |
| 18 | Delaware | 1.653 | | 1.468 | | 64 | Porter | 1.890 | | 1.750 | |
| 19 | Dubois | 1.501 | | 1.355 | | 65 | Posey | 1.486 | | 1.398 | |
| 20 | Elkhart | 1.722 | | 1.620 | | 66 | Pulaski | -- | | 1.222 | |
| 21 | Fayette | 1.479 | | 1.386 | | 67 | Putnam | 1.499 | | 1.373 | |
| 22 | Floyd | 1.474 | | 1.473 | | 68 | Randolph | 1.305 | | 1.225 | |
| 23 | Fountain | 1.526 | | 1.198 | | 69 | Ripley | 1.416 | | 1.342 | |
| 24 | Franklin | 1.473 | | 1.325 | | 70 | Rush | 1.347 | | 1.275 | |
| 25 | Fulton | 1.307 | | 1.223 | | 71 | St Joseph | 1.760 | | 1.466 | |
| 26 | Gibson | 1.402 | | 1.241 | | 72 | Scott | 1.774 | | 1.604 | |
| 27 | Grant | 1.528 | | 1.489 | | 73 | Shelby | 1.568 | | 1.509 | |
| 28 | Greene | 1.354 | | 1.293 | | 74 | Spencer | 1.543 | | 1.307 | |
| 29 | Hamilton | 1.850 | | 1.800 | | 75 | Starke | 1.510 | | 1.456 | |
| 30 | Hancock | 1.831 | | 1.806 | | 76 | Steuben | 1.420 | | 1.395 | |
| 31 | Harrison | 1.643 | | 1.430 | | 77 | Sullivan | 1.258 | | 1.165 | |
| 32 | Hendricks | 1.775 | | 1.650 | | 78 | Switzerland | -- | | 1.140 | |
| 33 | Henry | 1.461 | | 1.374 | | 79 | Tippecanoe | 1.687 | | 1.465 | |
| 34 | Howard | 1.775 | | 1.650 | | 80 | Tipton | 1.349 | | 1.322 | |
| 35 | Huntington | 1.351 | | 1.283 | | 81 | Union | -- | | 1.263 | |
| 36 | Jackson | 1.545 | | 1.379 | | 82 | Vanderburg | 1.386 | | 1.331 | |
| 37 | Jasper | 1.494 | | 1.425 | | 83 | Vermillion | 1.242 | | 1.166 | |
| 38 | Jay | 1.328 | | 1.229 | | 84 | Vigo | 1.368 | | 1.333 | |
| 39 | Jefferson | 1.709 | | 1.280 | | 85 | Wabash | 1.483 | | 1.353 | |
| 40 | Jennings | 1.625 | | 1.527 | | 86 | Warren | -- | | 1.238 | |
| 41 | Johnson | 1.850 | | 1.755 | | 87 | Warrick | 1.669 | | 1.641 | |
| 42 | Knox | 1.333 | | 1.220 | | 88 | Washington | 1.550 | | 1.348 | |
| 43 | Kosciusko | 1.695 | | 1.578 | | 89 | Wayne | 1.379 | | 1.365 | |
| 44 | Lagrange | -- | | 1.531 | | 90 | Wells | 1.523 | | 1.384 | |
| 45 | Lake | 1.715 | | 1.534 | | 91 | White | 1.495 | | 1.334 | |
| 46 | LaPorte | 1.630 | | 1.462 | | 92 | Whitley | 1.453 | | 1.436 | |

to account for the fact that a highway section may go through more than one functional classification zone. There are twelve functional classes, as shown in Table 2.2. For each highway section a factor for each functional class was developed as follows:

$$R_i = \frac{LM_i * ADT_i}{\Sigma (LM_i * ADT_i)} \qquad (2.2)$$

where,

$R_i$ = the fraction of a section's ADT contributed by the $i^{th}$ functional class.

$LM_i$ = portion of a section length (lane miles) that lies within the $i^{th}$ functional class.

$ADT_i$ = average daily traffic on the portion of a highway section that lies within the $i^{th}$ functional class.

The reason for including such a distribution of the ADT values among functional classes (if there is more than one within the same section) is that the percent of trucks differs significantly from one functional class to another. Without separating ADT by functional class, the estimated equivalent axle load (EAL) values for that section might be subjected to a considerable error.

## 2.3 Percent of Trucks

To convert the ADT value of a section to its corresponding EAL value, the percent of trucks should be known. Several

Table 2.2 IDOH Highway Functional Classes

| Area | Code | Functional Class |
|---|---|---|
| Rural | 1 | Interstate |
| | 2 | Other Rural Principal Arterials |
| | 3 | Rural Minor Arterials |
| | 4 | Rural Major Collectors |
| | 5 | Rural Minor Collectors |
| | 6 | Local Roads |
| Urban | 7 | Interstate |
| | 8 | Other Freeways and Expressways |
| | 9 | Other Urban Principal Arterials |
| | 10 | Minor Arterial Streets |
| | 11 | Collector Streets |
| | 12 | Local Streets |

factors should be considered when determining the percent of trucks, such as highway type, location within a highway type, and the year at which the percent of trucks was estimated. These factors were considered in this research through the use of the manual vehicle classification studies done by the IDOH during the period 1978-1981. Number of trucks is defined as the summation of number of major four truck types: single unit trucks; tractor semi-trailer combinations; semi-trailer trailer; and truck and trailer (based on FHWA classification for truck weight studies).

Six highway classes were considered in the IDOH manual vehicle classification studies:

1. Federal Aid Interstate Rural;
2. Federal Aid Interstate Urban;
3. Federal Aid Primary Rural;
4. Federal Aid Primary Urban;
5. Federal Aid Secondary Rural; and
6. Federal Aid Urban.

These six highway systems constitute about 90% of the total miles traveled in Indiana for 1982 (82,83). For each highway system a set of counting locations was established. The counting locations along with the corresponding percent of trucks for 1978-81 studies are listed in Table 2.3.

The major observations arrived after examining the values in Table 2.3 are: (i) for the same location within a highway system, the change in percent of trucks is small from year to year; (ii)

Table 2.3 Percent of Trucks By Highway System By Location.

| Highway System | Station No. | County No. | Percent of Trucks | | | | Average |
|---|---|---|---|---|---|---|---|
| | | | 1978 | 1979 | 1980 | 1981 | |
| Interstate Rural | 64 | 31 | 32 | 34 | 32 | 30 | 32.00 |
| | 164 | 26 | 39 | — | 35 | -- | 37.00 |
| | 65 | 36 | 29 | 31 | 33 | 31 | 31.00 |
| | 165 | 45 | 27 | 31 | 26 | 29 | 28.25 |
| | 69 | 35 | 30 | 33 | 33 | 29 | 31.25 |
| | 70 | 89 | 34 | 39 | 36 | 34 | 35.75 |
| | 170 | 67 | 37 | — | 36 | -- | 36.50 |
| | 270 | 30 | 33 | — | 39 | — | 36.00 |
| | 470 | 11 | — | — | -- | 34 | 34.00 |
| | 74 | 15 | 20 | 26 | 25 | 21 | 23.00 |
| | 774 | 23 | 31 | 38 | 34 | 34 | 34.25 |
| | 94 | 64 | 29 | 30 | 27 | 24 | 27.50 |
| | Average[1] | | 30 | 32 | 32 | 29 | 30.75 |
| Interstate Urban | 565 | 49 | 8 | — | 8 | — | 8.00 |
| | 180 | 45 | 29 | — | 25 | -- | 27.00 |
| | 865 | 22 | — | — | — | 22 | 22.00 |
| | 365 | 49 | 28 | -- | 10 | -- | 19.00 |
| | 465 | 49 | 12 | — | 10 | -- | 11.00 |
| | Average | | 18 | -- | 15 | 22 | 18.33 |
| Primary Rural | 41 | 45 | 19 | — | 20 | — | 19.50 |
| | 141 | 42 | 20 | -- | 23 | -- | 21.50 |
| | 43 | 54 | -- | 12 | -- | -- | 12.00 |
| | 50 | 15 | 9 | -- | 11 | -- | 10.00 |
| | 250 | 36 | — | -- | -- | 8 | 8.00 |
| | 54 | 77 | 13 | — | 10 | — | 11.50 |
| | 56 | 19 | 15 | — | 16 | -- | 15.50 |
| | 256 | 58 | -- | 8 | — | -- | 8.00 |
| | 66 | 82 | -- | -- | — | 5 | 5.00 |

Table 2.3 (Continued)

| Highway System | Station No. | County No. | Percent of Trucks | | | | Average |
|---|---|---|---|---|---|---|---|
| | | | 1978 | 1979 | 1980 | 1981 | |
| | 67 | 60 | — | — | 22 | — | 22.00 |
| | 3 | 70 | — | 15 | — | — | 15.00 |
| | 306 | 57 | 23 | 23 | 22 | 20 | 22.00 |
| | 406 | 20 | 29 | — | 25 | — | 27.00 |
| | 24 | 91 | 22 | — | 22 | — | 22.00 |
| | 30 | 2 | 28 | 30 | 27 | 25 | 27.50 |
| | 31 | 50 | 29 | — | 26 | — | 27.50 |
| | 32 | 68 | — | — | 8 | — | 8.00 |
| | 35 | 89 | — | — | — | 8 | 8.00 |
| | 137 | 55 | — | — | 12 | — | 12.00 |
| | 337 | 47 | — | — | 9 | — | 9.00 |
| | 437 | 55 | — | — | — | 11 | 11.00 |
| | 167 | 55 | — | — | 10 | — | 10.00 |
| | 135 | 31 | 8 | — | 8 | — | 8.00 |
| | 231 | 74 | — | — | 14 | — | 14.00 |
| | 531 | 79 | — | — | — | 13 | 13.00 |
| | 237 | 62 | — | — | 13 | — | 13.00 |
| | 421 | 66 | 18 | — | 22 | — | 20.00 |
| | 521 | 69 | 10 | — | 10 | — | 10.00 |
| | 621 | 46 | — | — | 13 | — | 13.00 |
| | 721 | 12 | — | — | — | 9 | 9.00 |
| | 235 | 88 | — | — | — | 15 | 15.00 |
| | Average | | 19 | 21 | 16 | 13 | 17.25 |
| Primary Urban | 15 | 27 | 6 | — | 5 | — | 5.50 |
| | 124 | 2 | — | 16 | — | — | 16.00 |
| | 25 | 79 | 7 | — | 8 | — | 7.50 |
| | 37 | 48 | 13 | — | 12 | 11 | 12.00 |
| | 137 | 53 | — | 11 | — | — | 11.00 |

Table 2.3 (Continued)

| Highway System | Station No. | County No. | Percent of Trucks | | | | Average |
|---|---|---|---|---|---|---|---|
| | | | 1978 | 1979 | 1980 | 1981 | |
| | 83 | 82 | 21 | 21 | 20 | 21 | 20.75 |
| | 46 | 3 | — | -- | -- | 5 | 5.00 |
| | Average | | 12 | 17 | 12 | 13 | 13.50 |
| Secondary Rural | 907 | 70 | 18 | — | — | -- | 18.00 |
| | 13 | 43 | 7 | 9 | 9 | — | 8.33 |
| | 16 | 9 | — | 16 | — | -- | 16.00 |
| | 131 | 3 | 7 | — | 6 | -- | 6.50 |
| | 236 | 68 | 19 | -- | 22 | -- | 20.50 |
| | 40 | 67 | 9 | 11 | 8 | 10 | 9.50 |
| | 140 | 30 | 5 | -- | 6 | — | 5.50 |
| | 52 | 79 | — | -- | -- | 14 | 14.00 |
| | 136 | 54 | 5 | — | 7 | -- | 6.00 |
| | 231 | 19 | -- | 15 | — | -- | 15.00 |
| | 446 | 53 | 5 | — | 6 | -- | 5.50 |
| | 68 | 26 | 9 | -- | -- | — | 9.00 |
| | Average | | 8 | 12 | 8 | 12 | 10.00 |
| Urban | 431 | 36 | — | -- | — | 5 | 5.00 |
| | 401 | 42 | 7 | 7 | 4 | 9 | 6.75 |
| | 62 | 22 | 4 | 4 | 3 | -- | 3.67 |
| | Average | | 5 | 7 | 4 | 6 | 5.50 |

1. The average is weighted by mileage covered by each station.

percent of trucks may significantly differ from location to location within the same functional class; and (iii) percent of trucks is significantly different from one highway system to another. For example, the primary rural system in Table 2.3 can be considered. While the maximum difference in percent of trucks in the four-year period at any station does not exceed 4% or 5%, the difference in percent of trucks for different stations (locations) may reach as high a value as 17%. Consequently, it was decided to consider the values for percent of trucks separately for different locations even within a given functional class. Also, no temporal variation was considered in percent of truck at a given location.

The counties that included one or more counting locations were considered first and the average percent of trucks for a particular location within a highway system was assumed to apply to all highway sections belonging to the highway system. The counties which had no counting locations were assigned values for percent of trucks based on their similarity in location with other counties where counting stations are located. To illustrate, the primary rural highway system can be considered. Counties with stations for that system are shown in Figure 2.4. The average percent of trucks in county number 2 (Allen) is 27.5 as shown in Table 2.2. The adjacent county number 90 (Wells) without any stations, was assigned the value as for county number 2. That means all highway sections in county number 92 belonging to primary rural highway system are assumed to have 27.5% trucks

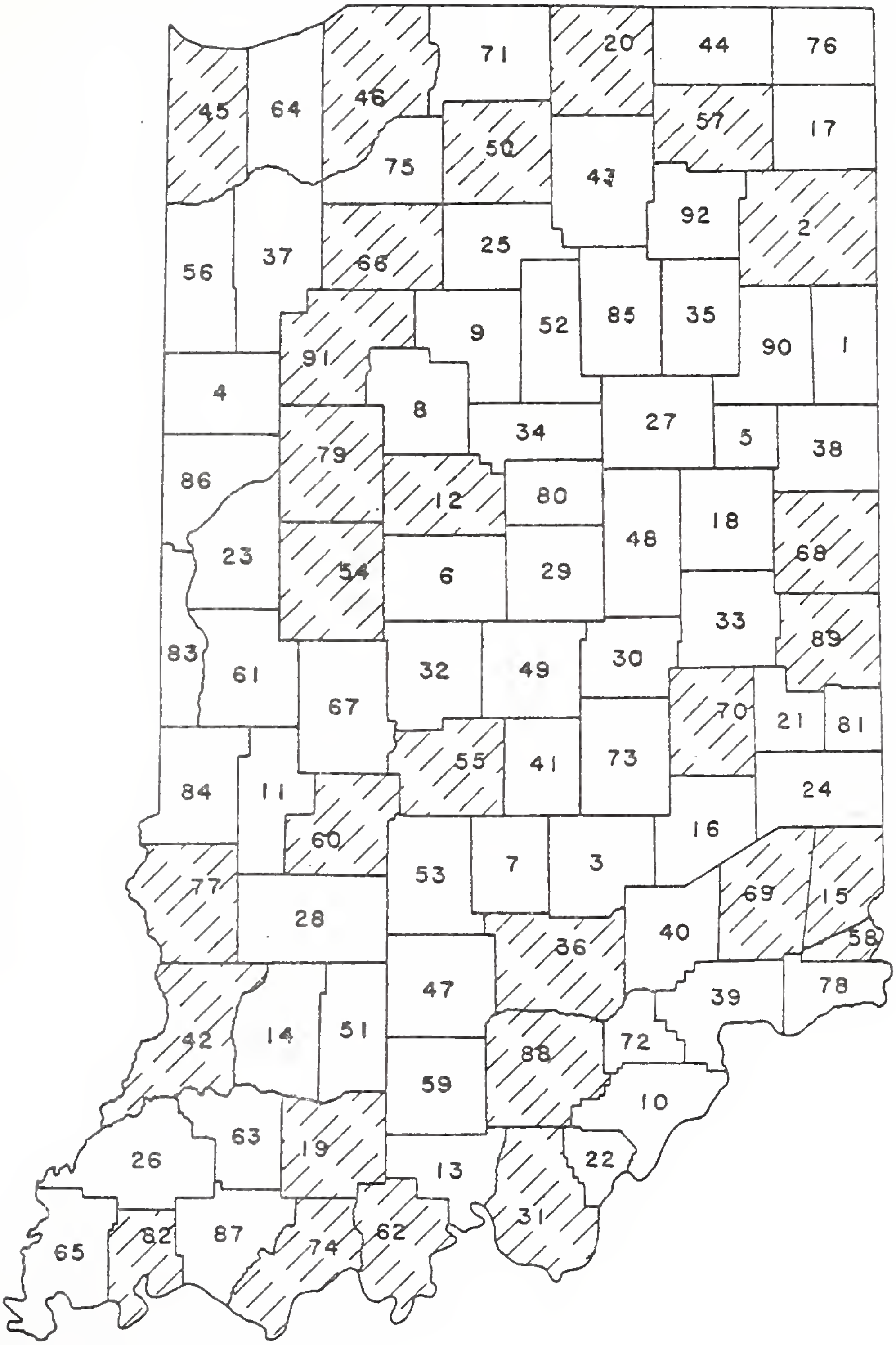

Figure 2.4 Illustration of Count Station Locations of the Primary Rural Highway System.

of their ADT values. The same procedure was applied to other counties.

At this point, ADT values for each highway section, percent of trucks, and updating factors were available in order to calculate the ADT values for any previous year.

## 2.4 Equivalent Axle Load Applications (EAL)

In order to have a full representation of different vehicle types and weight, a common traffic index, 18-kip equivalent single axle load (EAL-18) was used. The determination of the EAL-18 value for a pavement section requires information on the average daily traffic (ADT), vehicle type distribution, and the axle weight distribution for each vehicle type.

Vehicle type distribution as well as the axle weight distribution for each vehicle type were found to be available only through the truck weight studies done by the IDOH for the Federal Highway Administration (FHWA). From these studies, the EAL-18 value for each vehicle type could be obtained (Form W-4 was used for that purpose). Investigating the available information of seven truck weight studies conducted in 1981, 79, 77, 74, 73, 72, and 71, it was found that best results could be obtained by considering three highway systems: (i) Interstate (Rural and Urban); (ii) Other Rural; and (iii) Other Urban. For each highway system a set of weigh stations was used to weigh a sample of trucks using the system. The basic information obtained from each station in a given year included: (i) number of vehicles counted for each vehicle type; and (ii) on the basis of axle weight distribution of each vehicle type, the corresponding EAL-18 value computed for the total number of vehicles counted for each vehicle type for typical designs of rigid and flexible pavements.

In Table 2.4 is presented a summary of the data extracted from 1979-81 truck weight studies. Five Interstate stations were used. A ratio was developed to indicate the EAL-18 value corresponding to one vehicle in each vehicle type. For example, in Table 2.4, 2978 pickup trucks were counted in 1979 in station number 65. The corresponding EAL-18 for these 2978 vehicles is 162.9 for a typical rigid pavement design. Thus, a ratio of 0.055 (162.9/2978) was used, on the average, to convert one pickup truck to its EAL-18 equivalence. The average values for the entire Interstate system were obtained as the average of the values from different stations. Similarly, the 1977, 1974, 1973, 1972, and 1971 truck weight studies were considered and average ratios were developed for each year. Table 2.5 lists the average percentage of each vehicle type, rigid pavement ratio, and flexible pavement ratio for each year.

In the same way, the other two systems, Other Rural and Other Urban, were analyzed. Tables 2.6 and 2.7 summarize EAL-18 ratios for Other Rural and Other Urban systems, respectively. In addition, a combined conversion factor was developed for each year to convert truck traffic to corresponding EAL-18 value as follows:

Table 2.4 Illustration of the Equivalent Axle Load Factors for the Interstate System

| | | | | EAL[3] for all Vehicles Counted | | | | EAL/Vehicle | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station No. | Vehicle[2] Type | No. of Vehicles Counted | | 1979 | | 1981 | | 1979 | | 1981 | |
| | | 1979 | 1981 | Rigid | Flexible | Rigid | Flexible | Rigid | Flexible | Rigid | Flexible |
| 065 | 1 | 2978 | 2482 | 162.9 | 141.2 | 77.7 | 81.2 | 0.055 | 0.047 | 0.031 | 0.033 |
| | 2 | 4131 | 3942 | 5013.4 | 3137.6 | 4195.9 | 2655.0 | 1.214 | 0.760 | 1.064 | 0.670 |
| | 3 | 39 | 52 | 0 | 0 | 0 | 0 | 0.000 | 0.000 | 0.000 | 0.000 |
| | 4 | 276 | 188 | 3.9 | 3.9 | 63.7 | 67.1 | 0.014 | 0.014 | 0.340 | 0.360 |
| | Total | 7427 | 6664 | 5180.2 | 3282.7 | 4337.3 | 2803.3 | 0.700 | 0.442 | 0.650 | 0.421 |
| 069 | 1 | 1524 | 1460 | 49.5 | 50.3 | 51.2 | 47.9 | 0.032 | 0.033 | 0.035 | 0.033 |
| | 2 | 2047 | 2112 | 1832.9 | 1241.4 | 1857.7 | 1230.5 | 0.900 | 0.606 | 0.880 | 0.583 |
| | 3 | 82 | 58 | 116.4 | 121.0 | 54.0 | 57.3 | 1.420 | 1.476 | 0.930 | 0.983 |
| | 4 | 135 | 103 | 8.9 | 8.3 | 0 | 0 | 0.066 | 0.061 | 0 | 0 |
| | Total | 3788 | 3733 | 2007.7 | 1421 | 1962.9 | 1335.7 | 0.530 | 0.375 | 0.526 | 0.358 |
| 070 | 1 | 2777 | 2856 | 141.4 | 132.4 | 78.1 | 82.3 | 0.051 | 0.048 | 0.027 | 0.029 |
| | 2 | 5515 | 5446 | 6903.5 | 4356.7 | 5729.6 | 3656.8 | 1.252 | 0.800 | 1.052 | 0.671 |
| | 3 | 149 | 151 | 169.7 | 174.5 | 0 | 0 | 1.139 | 1.171 | 0 | 0 |
| | 4 | 213 | 268 | 3.3 | 3.4 | 0 | 0 | 0.015 | 0.016 | 0 | 0 |
| | Total | 8654 | 8721 | 7217.9 | 4667 | 5807.7 | 3739.1 | 0.834 | 0.539 | 0.666 | 0.429 |
| 165 | 1 | 3110 | 2946 | 80.4 | 79.2 | 103.2 | 98.1 | 0.026 | 0.025 | 0.035 | 0.033 |
| | 2 | 5038 | 4793 | 4836.0 | 3084.2 | 5458.1 | 3437.7 | 0.960 | 0.612 | 1.139 | 0.717 |
| | 3 | 58 | 71 | 50.7 | 63.2 | 0.0 | 0.0 | 0.874 | 1.010 | 0 | 0 |
| | 4 | 107 | 168 | 34.3 | 24.2 | 6.5 | 7.5 | 0.321 | 0.23 | 0.037 | 0.045 |
| | Total | 8313 | 7978 | 5001.4 | 3250.8 | 5567.8 | 3543.3 | 0.602 | 0.391 | 0.698 | 0.444 |
| 774 | 1 | 1106 | 1097 | 66.7 | 57.9 | 84.6 | 77.6 | 0.060 | 0.052 | 0.077 | 0.071 |
| | 2 | 1846 | 2091 | 2213.6 | 1392.9 | 2467.9 | 1545.3 | 1.199 | 0.755 | 1.180 | 0.739 |
| | 3 | 36 | 33 | 0 | 0 | 5.9 | 6.2 | 0 | 0 | 0.179 | 0.188 |
| | 4 | 102 | 128 | 7.7 | 8.1 | 0 | 0 | 0.075 | 0.079 | 0 | 0 |
| | Total | 3090 | 3349 | 2288 | 1458.9 | 2558.4 | 1629.1 | 0.740 | 0.472 | 0.828 | 0.527 |
| All Stations | 1 | 11495 | 10841 | 496.7 | 457.6 | 487.7 | 462.9 | 0.043 | 0.040 | 0.045 | 0.043 |
| | 2 | 18577 | 18384 | 20625.7 | 13161.1 | 19683.5 | 12528.1 | 1.110 | 0.708 | 1.071 | 0.681 |
| | 3 | 364 | 365 | 441.6 | 459.4 | 285.1 | 302.1 | 1.213 | 1.262 | 0.781 | 0.828 |
| | 4 | 833 | 855 | 56.1 | 53.8 | 160.2 | 170.3 | 0.067 | 0.065 | 0.187 | 0.199 |
| | Total | 31269 | 30445 | 21620.1 | 14131.9 | 20616.5 | 13463.4 | 0.691 | 0.452 | 0.677 | 0.442 |

[1] Source: 1981 Indiana Truck Weight Study

[2] Vehicle type 1: Single Unit Trucks
Vehicle type 2: Tractor Semi-Trailer Combinations
Vehicle type 3: Semi-Trailer Trailer
Vehicle type 4: Truck and Trailer

[3] Equivalent Axle Load Applications

Table 2.5 Average Equivalent Axle Load Factors Used In the Study for the Interstate System

| Year | Single Unit Trucks | | | Tractor Semi-Trailer Combinations | | | Semi-Trailer Trailer | | | Truck and Trailer | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent[2] | EAL[3] Ratio | | Percent | EAL Ratio | | Percent | EAL Ratio | | Percent | EAL Ratio | |
| | | Rigid | Flexible | | Rigid | Flexible | | Rigid | Flexible | | Rigid | Flexible |
| 81 | 35.6 | 0.045 | 0.043 | 60.4 | 1.071 | 0.681 | 1.2 | 0.781 | 0.828 | 2.8 | 0.187 | 0.199 |
| 79 | 36.7 | 0.043 | 0.040 | 59.4 | 1.110 | 0.708 | 1.2 | 1.213 | 1.262 | 2.7 | 0.076 | 0.065 |
| 77 | 39.4 | 0.045 | 0.042 | 57.8 | 1.161 | 0.740 | 0.9 | 1.762 | 1.766 | 1.9 | 0.400 | 0.290 |
| 74 | 29.3 | 0.073 | 0.070 | 65.3 | 1.014 | 0.662 | 1.9 | 1.334 | 1.328 | 3.5 | 0.[4] | 0. |
| 73 | 31.4 | 0.069 | 0.064 | 64.4 | 1.034 | 0.677 | 2.1 | 1.164 | 1.207 | 2.1 | 0.391 | 0.333 |
| 72 | 33.6 | 0.073 | 0.062 | 63.8 | 0.940 | 0.620 | 2.5 | 1.171 | 1.211 | 0.1 | 0. | 0. |
| 71 | 28.7 | 0.078 | 0.070 | 69.1 | 0.938 | 0.593 | 2.1 | 1.457 | 1.469 | 0.1 | 0. | 0. |

[1] Years when the Truck Weight Studies were performed in Indiana

[2] Percent of all trucks

[3] Equivalent Axle Load applications

[4] Zero means a very small conversion factor

Table 2.6 Average Equivalent Axle Load Factors Used In the Study for the Other Rural System.

| Year | Single Unit Trucks | | | Tractor Semi-Trailer Combinations | | | Semi-Trailer Trailer | | | Truck and Trailer | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent | EAL Ratio | | Percent | EAL Ratio | | Percent | EAL Ratio | | Percent | EAL Ratio | |
| | | Rigid | Flexible | | Rigid | Flexible | | Rigid | Flexible | | Rigid | Flexible |
| 81 | 73.31 | 0.062 | 0.054 | 24.21 | 0.887 | 0.577 | 0.30 | 0.927 | 0.927 | 2.18 | 0.021 | 0.021 |
| 79 | 67.87 | 0.036 | 0.032 | 29.83 | 0.954 | 0.615 | 0.30 | 0 | 0 | 2.00 | 0.119 | 0.119 |
| 77 | 52.37 | 0.032 | 0.032 | 45.85 | 1.203 | 0.782 | 0.44 | 0 | 0 | 1.34 | 0.245 | 0.161 |
| 74 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| 73 | 65.33 | 0.071 | 0.060 | 33.11 | 1.00 | 0.657 | 0.20 | 1.00 | 1.067 | 1.36 | 0.031 | 0.030 |
| 72 | 54.24 | 0.065 | 0.056 | 45.02 | 0.985 | 0.8738 | 0.64 | 1.904 | 1.917 | 0.10 | 0 | 0 |
| 71 | 48.54 | 0.058 | 0.051 | 50.82 | 1.273 | 0.820 | 0.540 | 0 | 0 | 0.10 | 0 | 0 |

Table 2.7 Average Equivalent Axle Load Factors Used In the Study for the Other Urban System

| Year | Single Unit Trucks | | | Tractor Semi-Trailer Combinations | | | Semi-Trailer Trailer | | | Truck and Trailer | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent | EAL Ratio | | Percent | EAL Ratio | | Percent | EAL Ratio | | Percent | EAL Ratio | |
| | | Rigid | Flexible | | Rigid | Flexible | | Rigid | Flexible | | Rigid | Flexible |
| 81 | 58.00 | 0.038 | 0.037 | 40.00 | 0.960 | 0.620 | 1.00 | 1.659 | 1.689 | 1.00 | 0.308 | 0.235 |
| 79 | 56.70 | 0.045 | 0.041 | 41.80 | 1.020 | 0.688 | 0.20 | 1.381 | 1.443 | 1.30 | 0.055 | 0.059 |
| 77 | 65.40 | 0.045 | 0.038 | 33.20 | 0.828 | 0.544 | 0.26 | 0.200 | 0.000 | 1.14 | 0 | 0 |
| 74 | 60.00 | 0.080 | 0.070 | 37.21 | 0.897 | 0.582 | 0.38 | 0.000 | 0.000 | 2.41 | 0 | 0 |
| 73 | 77.27 | 0.030 | 0.030 | 19.85 | 0.961 | 0.635 | 1.17 | 1.696 | 1.760 | 1.71 | 1.495 | 1.265 |
| 72 | 72.65 | 0.049 | 0.039 | 26.45 | 0.926 | 0.613 | 0.90 | 1.825 | 1.882 | 0.00 | 0 | 0 |
| 71 | 77.37 | 0.052 | 0.043 | 22.25 | 0.756 | 0.514 | 0.20 | 0.958 | 1.000 | 0.18 | 0.011 | 0.011 |

$$EALF = \frac{\sum_{i=1}^{4} P_i * EALR_i}{100} \qquad (2.3)$$

where,

EALF = equivalent axle load conversion factor;

$P_i$ = percent of the $i^{th}$ vehicle type,

$EALR_i$ = equivalent axle load ratio of the $i^{th}$ vehicle type.

Equation 2.3 was applied to both rigid and flexible pavements for the three highway systems for different years. A summary of these final conversion factors is given in Table 2.8. For years proceeding 1971, the average values were used.

## 2.5 Highway Section Characteristics

In order to obtain information on section length, section width, pavement type, pavement age, and so on, the highway inventory files of the IDOH were reviewed. However, the accuracy of the available data was found to be incompatible with the level required for this study. For instance, the pavement inventory files include data on section length, width, pavement type, etc., that were determined through a visual survey from an automobile. Consequently, it was decided to review the original road life records (plans) where the actual contract information is recorded. These records were found to be the most accurate source of required information for this study. Each highway section was considered individually and the number of contracts

Table 2.8 Final EAL Conversion Factors.

| Year | Interstate | | Other Rural | | Other Urban | |
|---|---|---|---|---|---|---|
| | Rigid | Flexible | Rigid | Flexible | Rigid | Flexible |
| 81 | 0.677 | 0.442 | 0.263 | 0.183 | 0.426 | 0.289 |
| 79 | 0.691 | 0.452 | 0.311 | 0.208 | 0.455 | 0.306 |
| 77 | 0.712 | 0.466 | 0.579 | 0.377 | 0.304 | 0.205 |
| 74 | 0.709 | 0.478 | 0.480 | 0.318 | 0.382 | 0.259 |
| 73 | 0.720 | 0.488 | 0.380 | 0.259 | 0.259 | 0.191 |
| 72 | 0.653 | 0.446 | 0.491 | 0.436 | 0.297 | 0.207 |
| 71 | 0.701 | 0.461 | 0.675 | 0.441 | 0.210 | 0.150 |
| Average | 0.695 | 0.462 | 0.450 | 0.317 | 0.333 | 0.230 |

within each section was identified. For each contract, the following information was obtained:

a. Contract length;

b. Contract width;

c. Pavement type and thickness (s);

d. Pavement age (number of years since construction or since last major maintenance, such as resurfacing or rehabilitation, was done).

For those highway sections with more than one contract, the information was aggregated based on pavement type. This way average width, average age, and so on, were identified for each pavement type within a highway section.

The first investigation of available pavement types indicated a wide variety of types particularly when different materials were considered. For example, an asphalt surface could be a Hot Asphalt Cement (HAC), Hot Asphalt Emulsion (HAE), simple surface treatment, seal coat, and so on. These different types along with the different categories of the underlying layers of rigid or flexible pavements resulted in a wide range of pavement type combinations. To include all different combinations would have required a very large number of sections, particularly when other factors such as age, traffic level, climate, and so on, were considered. As the purpose of this research was to provide general models for pavement maintenance prediction at a network level of management, it was decided to consider the major three pavement categories, flexible pavement, rigid pavement, and resurfaced pavement.

## 2.6 Routine Maintenance Expenditures

The Indiana Department of Highways (IDOH) keeps a detailed record of highway routine maintenance activities. These records are the compiled form of actual field information concerning all routine maintenance activities which are recorded on field crew day cards. This part of the research dealt only with pavement routine maintenance activities. In Table 2.9, the nine pavement maintenance activities considered in this study along with their code numbers and production units are listed.

The results from the field survey of the IDOH maintenance activities described in Reference 4 were used to review the accuracy of the available maintenance data. A comparison of the recorded maintenance data with the field survey information indicated a high degree of reliability for the recorded maintenance data.

The IDOH has 37 subdistricts in six districts within its jurisdiction. Each subdistrict is responsible for a set of highway sections. A highway section is defined as the portion of a highway that lies within the boundaries of a county. Although a highway section may include a series of different contract sections with different pavement characteristics, the routine maintenance information is recorded on the basis of a highway

Table 2.9 Pavement Routine Maintenance Activities.

| Activity Name | Code Number | Production Units |
|---|---|---|
| Shallow Patching | 201 | Tons of mix |
| Deep Patching | 202 | Tons of mix |
| Premix Leveling | 203 | Tons of premix |
| Seal Coating | 205 | Lane-miles |
| Sealing Longitudinal Cracks and Joints | 206 | Linear Miles |
| Sealing Cracks | 207 | Lane-miles |
| Cutting Relief Joints | 209 | Linear feet |
| Joint and Bump Burning | 214 | Bumps removed |
| Others | 219 | Man-hours |

section. The appropriate data for the purpose of this study would have been maintenance records by contract section. A contract section indicates that portion of a highway pavement that is contracted out to one contractor for a specific activity and thus the pavement characteristics within a contract section are generally uniform.

To comply with the maintenance recording system as described above, the highway system in Indiana was divided into 768 highway sections. The Interstate system consists of 62 highway sections and Other State Highway system of 706 sections.

Routine maintenance activities included in this study included pavement routine maintenance records for the last four fiscal years (1980-83). These records were aggregated for each of the 768 highway sections. The following information for each highway section was extracted:

i. Section Identification

  a. Section number

  b. Highway system

      Interstate

      Other State Highways

  c. Route number

  d. County number

  e. District number

ii. For each of the four years (1980-83) the following information was summarized for each of the nine pavement maintenance activities:

a. Total production units

b. Total man-hours

c. Types and quantities of materials

Finally, the above information was used along with the appropriate unit costs to obtain the dollar value of maintenance activities performed on each highway section during each of the four fiscal years. The cost items considered were labor; materials (other than motor fuel); and the cost of motor fuel consumed by maintenance equipment fleet. The first two cost items were obtained directly from References 63, 64, and 65. Fuel consumption costs were also obtained from the results of the field study described in Chapter 4.

It should be noted here that pavement routine maintenance costs considered in this study included only the out-of-pocket field costs. In other words, these costs did not include administrative costs, equipment depreciation costs, fringe benefits for maintenance workers, and such other items. The reason for excluding these items from the cost figures is that there is a very low correlation between these items and the actual maintenance need of pavement sections. On the other hand, number of man_hours, number of production units of an activity, or degree of equipment use are direct indicators of actual degree of maintenance need.

The maintenance work done for each section was included in the data base in two forms: (i) in terms of dollars per lane-mile spent on each activity in each of the four fiscal years; and (ii) in terms of production units per lane-mile of each activity in each of the four fiscal years.

## 2.7 Climatic Zones

One of the major factors causing pavement distresses is the climatic environment. A pavement is affected not only by the weather, but also by the related factors such as deicing chemical agents. Based on the results of the study done at Purdue University for the IDOH (85), the state of Indiana was divided into three regional zones as shown in Figure 2.5. The division of the state into three geographical regions was possible due to the unique relationships among soil type, freezing index, and precipitation. The southern boundary of the northern region extends on a line from just north of Kentland in Newton County through Monticello in White County north of Marion County. The southern boundary of the central region extends from a line just south of Newport in Vermillion County through a point north of Franklin in Johnson County and from there north of Lawrenceburg in Dearborn County.

## 2.8 Data Base Illustration

The compiled data base included the following information for each highway section:

1. general information:
   - a. section number

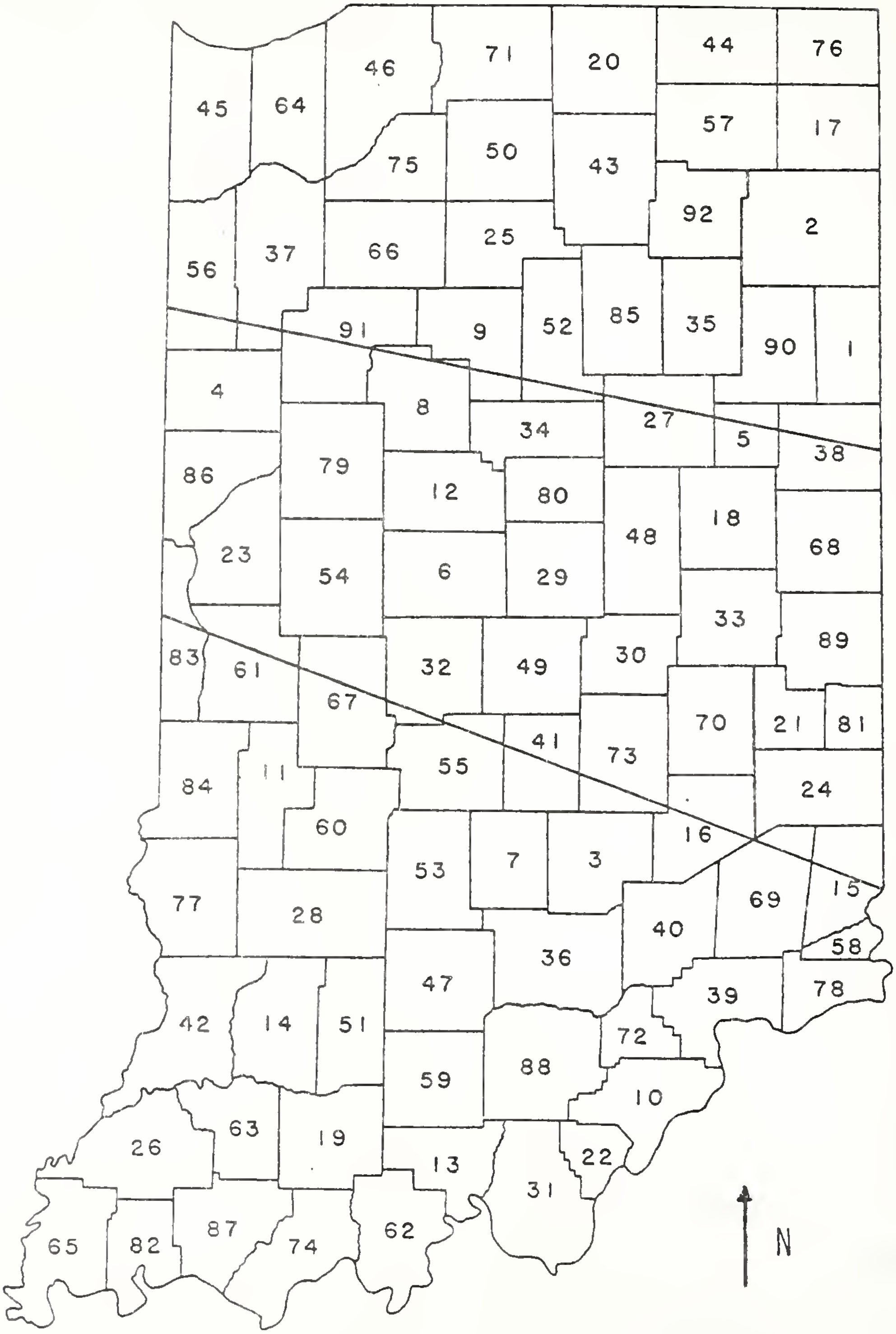

Figure 2.5 Climatic Zones.

b. highway type (Interstate, SR, or US)

c. highway number

d. county number

e. district number

f. ADT (1978)

g. ADT conversion factor $= \frac{ADT_{82}}{ADT_{78}}$

h. section length (lane-miles)

i. regional zone (1-3)

j. number of contracts (if the section includes more than one contract)

k. number of pavement types within the section (if more than one pavement type)

ii. pavement type information (repeated for each pavement type)

a. pavement code (1: flexible pavement, 2: rigid pavement, and 3: resurfaced pavement)

b. age, year at which the last major improvement (resurfacing, rehabilitation, and so on) took place.

c. average base course thickness

d. average surface thickness

e. length (lane-miles)

f. percent of total section length

iii. ADT yearly conversion factors for the urban portions

This record includes 18 updating factor to convert the 1978 ADT to the ADT values for 1965 through 1982.

iv. ADT yearly conversion factors for the rural portions same as in iii.

v. distribution of vehicle-miles traveled by functional class

This record includes twelve fractions, each of them representing the fraction of total vehicle-miles traveled for a particular functional class. These factors are computed by Equation 2.2 and the 12 functional classes are listed in Table 2.2.

vi. Percent of trucks

This record includes twelve values for percent of trucks, one for each functional class.

vii. EAL Conversion factors

EAL conversion factors are given in six cards. The first is for the Interstate flexible pavements, the second for the Interstate rigid pavement, the third and fourth for Other Rural system, and the fifth and sixth for Other Urban system. Each card contains 18 conversion factors, the first to convert the 1965 truck count to the corresponding EAL and the factor 18th for the 1982 EAL.

viii. Pavement routine maintenance expenditure matrix

This matrix consists of 36 elements in 4 records. Four records represent four fiscal years and nine elements represent the dollars per lane-mile per year spent on nine maintenance activities. It should be noted here that all expenditure data were converted to the 1982-83 unit costs.

ix. Pavement routine maintenance production unit matrix

It is same as the expenditure matrix but with production units per lane-mile per year as the matrix elements instead of the dollars per lane-mile per year.

## 2.9 Computation of Cumulative EAL

The EAL for any year is a representation of the level of traffic using a highway section, taking into consideration different vehicle types and weights. However, a pavement distress is the result of cumulative EAL over time (age). A set of steps was used to calculate the accumulated EAL for each highway section under consideration, as listed below:

1. Pavement age as of 1982 was taken as the number of years since the last major maintenance activity on the section.
2. For each year within the pavement age, the following computations were done:
   a. The base year ADT (1978) was updated to the year under consideration using the ADT conversion factor described

earlier.

b. The weighted average percent of trucks was calculated as follows:

$$PTR = \sum_{i=1}^{12} P_i \; R_i \tag{2.4}$$

where,

PTR = average percent of trucks for the entire section;

$P_i$ = average percent of trucks in the ith functional class;

$R_i$ = fraction of total vehicle-miles traveled in the ith functional class.

3. The EAL value for the year under consideration was calculated as follows:

$$EAL = ADT * PTR * EALF * 365 \tag{2.5}$$

where,

EAL = equivalent axle load application for the year under consideration;

ADT = updated average daily traffic for the year under consideration (from Step 2a.);

EALF = equivalent axle load conversion factor for year under consideration (from Table 2.7);

PTR = average percent of trucks for the entire section (from Equation 2.4).

4. Steps 2 and 3 were repeated for all years included in the pavement age. The EAL values for the individual years were then summed to obtain the total accumulated EAL during the pavement age.

5. If more than one pavement type existed in the same section, the above process was repeated for each pavement type.

## 2.10 Chapter Summary

The current two categories of the state highway system of Indiana, Interstate and Other State Highways, were further subdivided by geographic location (climatic zones) and by pavement type. Two geographic locations, north and south, were included to reflect the major climatic differences in Indiana. The pavement types considered were: flexible pavement, rigid pavement, and resurfaced pavement.

The entire state highway system was divided into 820 highway section (a highway section is the portion of a highway within county limits). For each of the 820 sections, four major groups of information were summarized: traffic, pavement characteristics, climatic zone, and pavement routine maintenance records.

Traffic information included average annual daily traffic (AADT), percent of trucks, and the equivalent axle load (EAL) applications. The EAL was used as the common traffic index to account for different vehicle types and weights. Pavement characteristics included pavement type, age, and layer thickness(es) and types. Climatic zones included geographical areas with similar climate in terms of snowfall, rainfall, temperature difference and so on. Finally, pavement routine maintenance records included total production units, total man-hours, and types and quantities of materials. Pavement maintenance information was summarized for each highway section by activity and by fiscal year. Pavement maintenance activities consisted of the following: shallow patching, deep patching, premix leveling, seal coating, sealing longitudinal cracks and joints, sealing cracks, cutting relief joints, joint and bump burning, and others. The unit costs and different resource consumption rates for these activities were obtained from the results of the first phase of the study as well as from available information at the IDOH. An important feature of the study was that it used only those data that are routinely collected by the state.

# CHAPTER 3

# TRENDS OF PAVEMENT MAINTENANCE EXPENDITURE AND RESOURCE USE

## 3.1 Introduction

In this chapter, the trends of annual total maintenance expenditure as well as trends of individual activity expenditures including labor and materials consumption rates during the four fiscal years 1980-83 are analyzed. The purpose of conducting such an analysis is to provide insight in the pattern of resources consumption over time so that any significant change in maintenance technology or management can be detected. It is believed that such information should be carefully considered in developing prediction models for routine maintenance needs.

## 3.2 Trends of Pavement Maintenance Costs

Pavement maintenance costs were computed for each highway section in terms of dollars per lane-mile. To avoid changes in unit prices from year to year, all costs were converted to 1982-83 dollars. After careful investigation of pavement maintenance files, 768 sections (62 in IS and 706 in OSHS) were found to be eligible for this analysis.

Table 3.1 presents a summary of these results. For example, in 1980 the average cost of activity 201 (shallow patching) when performed the Interstate System (IS) was 45 dollars per lane-

Table 3.1 Trends of Pavement Maintenance Costs[1]

| | Average Cost[2] ($/Lane mile/year) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Interstate | | | | Other State Highways | | | |
| Activity No.[3] | F.Y.[3] 1980 | F.Y. 1981 | F.Y. 1982 | F.Y. 1983 | F.Y. 1980 | F.Y. 1981 | F.Y. 1982 | F.Y. 1983 |
| 201 | 45 | 60 | 69 | 63 | 114 | 91 | 135 | 94 |
| 202 | 17 | 30 | 20 | 26 | 17 | 32 | 19 | 13 |
| 203 | 4 | 6 | 10 | 1 | 33 | 30 | 18 | 37 |
| 205 | N.A.[4] | N.A. | N.A. | N.A. | 70 | 43 | 71 | 55 |
| 206 | 44 | 59 | 24 | 26 | 7 | 7 | 8 | 9 |
| 207 | 33 | 48 | 35 | 73 | 98 | 74 | 65 | 98 |
| 209 | 8 | 9 | 4 | 4 | 5 | 4 | 4 | 4 |
| 214 | 4 | 4 | 9 | 7 | 10 | 8 | 15 | 8 |
| 219 | 18 | 11 | 11 | 9 | 10 | 8 | 15 | 8 |
| Total | 163 | 227 | 180 | 208 | 358 | 296 | 343 | 325 |

[1] Based on 62 Interstate sections and 706 OSH sections.

[2] In 1982-1983 dollars.

[3] Fiscal year.

[4] Not available.

mile, while $114/lane mile was the average cost for Other State Highway System (OSHS).

It was observed, in general, that the average total cost of pavement maintenance of the IS is less than that of OSHS. From Table 3.1, it can be seen that the average total cost on OSHS is 30% to 120% higher than that on IS. This trend is graphically presented in Figure 3.1 where the cumulative distribution of average total costs for the two highway systems are plotted. For instance, 10% of the total IS lane-miles received pavement maintenance with average cost of $295/lane-mile/year, while 10% of the total lane-miles of OSHS received an average of $547/lane-mile/year, in the last four years. The reason the IS sections have lower maintenance costs per lane-mile can partly be traced to the fact that the IS receives more dollars per lane-mile of major maintenance activities, such as resurfacing, rehabilitation, and reconstruction, thus reducing the need for frequent routine maintenance activities.

The activities contributing most to the total pavement maintenance costs are patching (activities 201 and 202) and sealing (activities 206 and 207). About 85% of the total cost of IS pavement maintenance was spent on these four activities during 1980, while 87%, 82%, and 90%, was spent during 1981, 1982 and 1983, respectively. For the OSHS, these percentages were 66%, 69%, 66%, and 66% for 1980, 1981, 1982, and 1983, respectively.

The single activity with the highest portion of pavement

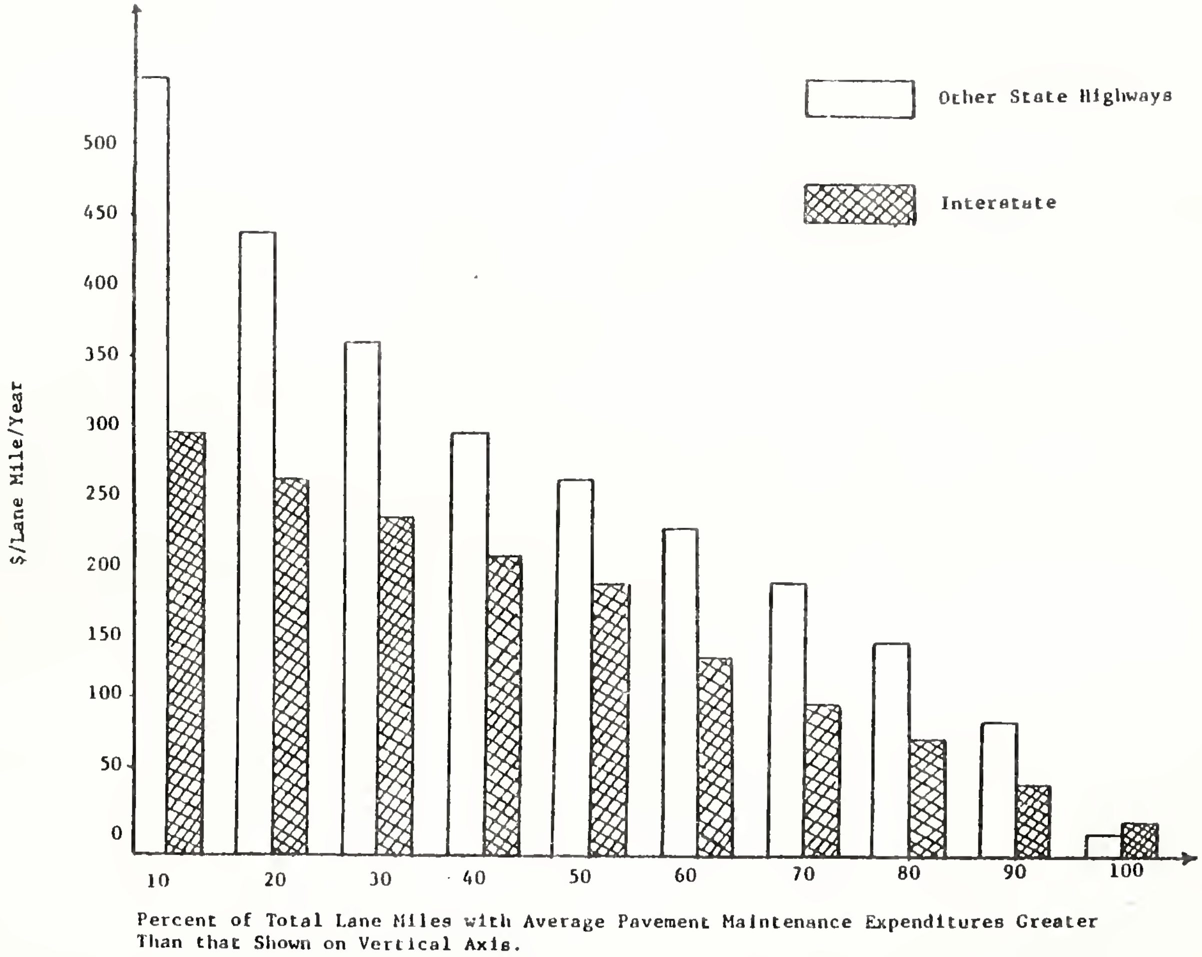

Figure 3.1 Lane-Miles - Maintenance Expenditures Distribution

routine maintenance cost is shallow patching (activity 201). The share of this activity in the total cost was 27%, 28%, 38%, and 30% during 1980, 1981, 1982, and 1983, respectively for the IS. The corresponding percentages for the OSHS are 32%, 31%, 40% and 29%, respectively.

The implication of these results is that in developing routine maintenance prediction models, a separate consideration should be made for IS and OSHS. In addition, the results clearly show that the accuracy of prediction models would depend largely on the accuracy of the prediction of patching and sealing activity needs.

## 3.3 Trends in Labor Consumption Rates

In order to analyze the labor requirements of pavement maintenance activities, average labor consumption rates in terms of man-hours required to produce one unit of a particular activity were calculated for each of the highway systems separately for each of the four years as follows:

$$L_{ijk} = \frac{\Sigma\, l_{ijkm}}{n_{ijk}} \qquad (3.1)$$

where,

$L_{ijk}$ = average labor consumption rate in terms of number of man-hours used to produce one production unit of the $i^{th}$ activity during the $j^{th}$ year on the $k^{th}$ highway system;

$l_{ijkm}$ = average labor consumption rate in terms of number of man-hours used to produce one production unit of $i^{th}$ activity during the $j^{th}$ year on the $m^{th}$ highway section of the $k^{th}$ highway system; and

$n_{ijk}$ = total number of highway sections in the $k^{th}$ highway system that received the $i^{th}$ activity during the $j^{th}$ year.

Table 3.2 presents a summary of the average labor consumption rates computed by use of Equation 3.1. It can be noted that the labor consumption rates of patching activities (201 and 202) on the IS are higher than those on the OSHS. On the other hand, the rates of sealing activities (206 and 207) on the IS are less than those on the OSHS. This apparent discrepancy can be explained by the fact that both activities on the IS require more elaborate safety arrangements during maintenance operations causing higher man-hours. However, the relative magnitude of cracks sealed per lane-mile in the OSHS is much higher than that in the IS and this causes a higher net need for man-hours for sealing activities on the OSHS.

## 3.4 Trends in Materials Use

The rates of materials consumption in various activities were analyzed by examining the average rates of consumption of different material types by highway system for each of the four years, as presented in Equation 3.2.

Table 3.2 Trends of Labor Productivity

| Activity No. | Man-Hours/Production Unit (Number of Sections) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Interstate | | | | Other State Highways | | | |
| | F.Y.[1] 1980 | F.Y. 1981 | F.Y. 1982 | F.Y. 1983 | F.Y. 1980 | F.Y. 1981 | F.Y. 1982 | F.Y. 1983 |
| 201 | 16.63<br>(48) | 15.87<br>(44) | 14.35<br>(48) | 17.62<br>(44) | 12.03<br>(570) | 12.72<br>(548) | 12.23<br>(579) | 12.77<br>(572) |
| 202 | 14.26<br>(23) | 9.51<br>(27) | 13.44<br>(26) | 11.12<br>(23) | 9.68<br>(204) | 10.41<br>(225) | 9.51<br>(220) | 8.78<br>(205) |
| 203 | 8.21<br>(8) | 10.59<br>(12) | 5.49<br>(13) | 10.58<br>(5) | 4.87<br>(93) | 4.54<br>(112) | 5.80<br>(103) | 4.41<br>(103) |
| 205 | N.A.[2]<br>(0) | N.A.<br>(0) | N.A.<br>(0) | N.A.<br>(0) | 39.32<br>(64) | 29.92<br>(51) | 29.24<br>(48) | 28.00<br>(59) |
| 206 | 9.35<br>(31) | 9.79<br>(40) | 9.16<br>(20) | 9.13<br>(23) | 11.44<br>(74) | 10.13<br>(77) | 10.51<br>(83) | 8.66<br>(100) |
| 207 | 36.15<br>(29) | 24.22<br>(31) | 23.57<br>(24) | 25.93<br>(22) | 31.81<br>(356) | 32.11<br>(333) | 29.39<br>(324) | 29.95<br>(382) |
| 209 | 0.51<br>(11) | 0.62<br>(15) | 0.59<br>(10) | 0.61<br>(9) | 0.63<br>(97) | 0.94<br>(84) | 0.51<br>(87) | 0.55<br>(79) |
| 214 | 6.46<br>(14) | 6.95<br>(15) | 7.50<br>(12) | 5.95<br>(15) | 5.21<br>(128) | 5.49<br>(179) | 4.61<br>(165) | 5.07<br>(169) |
| 219 | 1.00<br>(24) | 1.00<br>(26) | 1.00<br>(27) | 1.00<br>(26) | 1.00<br>(171) | 1.00<br>(186) | 1.00<br>(191) | 1.00<br>(184) |

[1] Fiscal year.

[2] Not available.

$$R_{ijkl} = \frac{\Sigma\ Q_{ijklm}}{n_{ijkl}} \tag{3.2}$$

where,

$R_{ijkl}$ = average rate of consumption of the $l^{th}$ material type in terms of number of material units used to produce one production unit of the $i^{th}$ activity during the $j^{th}$ year on the $k^{th}$ highway system;

$Q_{ijklm}$ = average rate of consumption of the $l^{th}$ material type in terms of number of material units used to produce one production unit of the $i^{th}$ activity during the $j^{th}$ year on the $m^{th}$ highway section of the $k^{th}$ highway system; and

$n_{ijkl}$ = total number of highway sections in the $k^{th}$ highway system that received the $l^{th}$ material while performing the $i^{th}$ activity during the $j^{th}$ year.

In addition, the frequency of use of each material type was calculated for each activity type by highway system for each of the four years as follows:

$$F_{ijkl} = \frac{n_{ijkl}}{N_{ijk}} \tag{3.3}$$

where,

$F_{ijkl}$ = frequency of use of $l^{th}$ material type when used in the $i^{th}$ activity during the $j^{th}$ year on the $k^{th}$ highway system; and

$N_{ijk}$ = total number of sections in the $k^{th}$ highway system that received the $i^{th}$ activity during the

$j^{th}$ year.

In Table 3.3 are shown the average rates of material consumption and frequencies of use. For example, 5.14 gallons of bituminous material were used on the average during 1980 on the IS to produce one ton of activity 201 (shallow patching ). The frequency of use of this type of material was 0.77, indicating that in each 100 jobs of shallow patching performed on the IS during 1980, there were 77 jobs that used bituminous material, and 23 jobs that did not use this type of material.

A definite trend was observed in the use of bituminous mixtures in patching activities (201 and 202). A significant increase took place in the use of salvage and cold bituminous mixtures to replace the conventional hot bituminous mixtures. For example, in 1980 for shallow patching activity (No. 201), salvage bituminous mixtures were used very rarely; they were not used at all on the IS and were used in only 1% of the OSHS jobs. However, in 1983, salvage and cold bituminous mixtures were used in 89% of the shallow patching jobs on the IS and in 100% of the OSHS jobs. At the same time, a gradual decrease took place in the use of conventional bituminous mixtures and bituminous materials. For example, bituminous mixtures were used in 100% of the shallow patching jobs on the IS during 1980 as compared to 90% in 1983. The corresponding percentages for OSHS jobs were 100% in 1980 and 82% in 1983. The use of bituminous materials, was also reduced during this period. In 1980, 77% of the shallow patching jobs on the IS used bituminous materials, while in 1983

Table 3.3 Materials Use in Pavement Routine Maintenance Activities

| Material Name (measurement unit) | Interstate |  |  |  | Other State Highways |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  | F.Y.[1] 80 | F.Y. 81 | F.Y. 82 | F.Y. 83 | F.Y. 80 | F.Y. 81 | F.Y. 82 | F.Y. 83 |
|  | Shallow Patching (Production Unit = ton of mix) |  |  |  |  |  |  |  |
| Aggregate or Backfill Material (ton)<br>Rate[2]<br>Frequency[3] | 0.26<br>(0.26) | 0.19<br>(0.24) | 0.17<br>(0.32) | 0.48<br>(0.32) | 0.29<br>(0.23) | 0.45<br>(0.17) | 0.25<br>(0.26) | 0.26<br>(0.21) |
| Seal Cover Aggregate (ton)<br>Rate<br>Frequency | 0.10<br>(0.45) | 0.58<br>(0.46) | 0.09<br>(0.44) | 0.06<br>(0.41) | 0.16<br>(0.34) | 0.24<br>(0.29) | 0.33<br>(0.32) | 0.13<br>(0.21) |
| Bituminous Material (gallon)<br>Rate<br>Frequency | 5.14<br>(0.77) | 10.59<br>(0.43) | 5.11<br>(0.40) | 3.37<br>(0.51) | 4.90<br>(0.65) | 6.19<br>(0.41) | 4.97<br>(0.38) | 4.16<br>(0.31) |
| Bituminous Mixture (ton)<br>Rate<br>Frequency | 1.00<br>(1.00) | 0.92<br>(1.00) | 0.61<br>(0.92) | 0.61<br>(0.63) | 0.95<br>(1.00) | 0.96<br>(1.00) | 0.58<br>(0.63) | 0.61<br>(0.82) |
| Salvage Bituminous Mixture (ton)<br>Rate<br>Frequency | 0.00<br>(0.00) | 0.05<br>(0.11) | 0.57<br>(0.92) | 0.54<br>(0.89) | 0.13<br>(0.01) | 0.19<br>(0.05) | 0.61<br>(1.00) | 0.62<br>(1.00) |
|  | Deep Patching (Production Unit = ton of mix) |  |  |  |  |  |  |  |
| Aggregate or Backfill Material (ton)<br>Rate<br>Frequency | 0.39<br>(0.40) | 0.55<br>(0.34) | 0.55<br>(0.32) | 0.21<br>(0.46) | 1.16<br>(0.38) | 0.72<br>(0.35) | 0.89<br>(0.35) | 0.99<br>(0.34) |
| Seal Cover Aggregate (ton)<br>Rate<br>Frequency | 0.11<br>(0.43) | 0.03<br>(0.34) | 0.07<br>(0.20) | 0.04<br>(0.30) | 0.11<br>(0.21) | 0.31<br>(0.28) | 0.11<br>(0.15) | 0.17<br>(0.13) |
| Bituminous Material (gallon)<br>Rate<br>Frequency | 4.30<br>(0.65) | 0.91<br>(0.44) | 2.00<br>(0.42) | 1.32<br>(0.27) | 2.46<br>(0.37) | 2.88<br>(0.38) | 2.28<br>(0.38) | 1.75<br>(0.34) |
| Bituminous Mixture (ton)<br>Rate<br>Frequency | 0.98<br>(1.00) | 0.99<br>(1.00) | 0.87<br>(1.00) | 0.89<br>(1.00) | 0.99<br>(1.00) | 0.98<br>(1.00) | 0.93<br>(1.00) | 0.85<br>(1.00) |
| Salvage Bituminous Mixture (ton)<br>Rate<br>Frequency | 0.00<br>(0.00) | 0.12<br>(0.11) | 0.54<br>(0.32) | 0.45<br>(0.51) | 0.86<br>(0.03) | 0.64<br>(0.05) | 0.69<br>(0.38) | 0.78<br>(0.47) |
|  | Premix Leveling (Production Unit = ton of mix) |  |  |  |  |  |  |  |
| Bituminous Material (gallon)<br>Rate<br>Frequency | 4.04<br>(0.85) | 3.09<br>(0.67) | 3.24<br>(0.91) | 4.19<br>(0.93) | 2.18<br>(0.76) | 3.15<br>(0.70) | 2.94<br>(0.63) | 2.03<br>(0.56) |
| Bituminous Mixture (ton)<br>Rate<br>Frequency | 1.00<br>(1.00) | 1.00<br>(1.00) | 1.00<br>(1.00) | 1.00<br>(1.00) | 1.00<br>(1.00) | 1.00<br>(1.00) | 1.00<br>(1.00) | 1.00<br>(1.00) |

Table 3.3 (Continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Seal Coating (Production Unit = lane mile) | | | | | | | |
| Seal Cover Aggregate (ton) | | | | | | | | |
| Rate | N.A.[4] | N.A. | N.A. | N.A. | 58.64 | 56.04 | 62.92 | 67.60 |
| Frequency | | | | | (0.88) | (1.00) | (1.00) | (0.96) |
| Bituminous Material (gallon) | | | | | | | | |
| Rate | N.A. | N.A. | N.A. | N.A. | 1148.02 | 1095.51 | 1261.55 | 1406.42 |
| Frequency | | | | | (1.00) | (1.00) | (1.00) | (1.00) |
| | Sealing Longitudinal Cracks and Joints (Production Unit = linear mile) | | | | | | | |
| Seal Cover Aggregate (ton) | | | | | | | | |
| Rate | 3.01 | 2.18 | 1.47 | 2.47 | 3.61 | 2.52 | 3.36 | 3.18 |
| Frequency | (0.62) | (0.81) | (0.65) | (0.86) | (0.95) | (0.93) | (0.95) | (0.92) |
| Bituminous Material (gallon) | | | | | | | | |
| Rate | 96.30 | 99.11 | 79.97 | 81.20 | 117.47 | 80.88 | 79.12 | 76.74 |
| Frequency | (1.00) | (1.00) | (1.00) | (1.00) | (0.95) | (1.00) | (1.00) | (1.00) |
| | Crack Sealing (Production Unit = lane mile) | | | | | | | |
| Seal Cover Aggregate (ton) | | | | | | | | |
| Rate | 4.17 | 1.91 | 2.63 | 2.45 | 4.84 | 4.77 | 4.81 | 4.68 |
| Frequency | (1.00) | (0.96) | (0.96) | (1.00) | (0.97) | (1.00) | (1.00) | (1.00) |
| Bituminous Material (gallon) | | | | | | | | |
| Rate | 100.58 | 69.98 | 65.82 | 84.59 | 119.47 | 125.82 | 133.27 | 128.70 |
| Frequency | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) |
| | Cutting Relief Joints (Production Unit = Linear foot) | | | | | | | |
| Seal Cover Aggregate (ton) | | | | | | | | |
| Rate | 0.01 | 0.01 | 0.00 | 0.02 | 0.05 | 0.01 | 0.03 | 0.01 |
| Frecuency | (0.62) | (0.83) | (0.00) | (0.47) | (0.28) | (0.16) | (0.17) | (0.19) |
| Performed Joint Filler (linear ft.) | | | | | | | | |
| Rate | 0.60 | 0.72 | 1.00 | 0.67 | 0.86 | 0.66 | 1.00 | 0.84 |
| Frequency | (0.74) | (1.00) | (0.97) | (0.93) | (0.55) | (0.63) | (0.69) | (0.74) |
| Bituminous Material (gallon) | | | | | | | | |
| Rate | 0.21 | 0.25 | 0.20 | 0.00 | 0.57 | 0.12 | 0.21 | 0.02 |
| Frequency | (1.00) | (0.62) | (0.44) | (0.00) | (0.55) | (0.47) | (0.34) | (0.15) |
| Bituminous Mixture (ton) | | | | | | | | |
| Rate | 0.02 | 0.01 | 0.00 | 0.00 | 0.02 | 0.03 | 0.00 | 0.06 |
| Frequency | (1.00) | (0.31) | (0.17) | (0.00) | (0.97) | (0.94) | (0.17) | (0.19) |
| Salvage Bituminous Mixture (ton) | | | | | | | | |
| Rate | 0.00 | 0.00 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| Frequency | (0.00) | (0.00) | (0.71) | (0.93) | (0.00) | (0.16) | (1.00) | (0.93) |
| | Joint and Bump Buring (Production Unit = Bump Removed) | | | | | | | |
| Seal Cover Aggregate (ton) | | | | | | | | |
| Rate | 0.10 | 0.17 | 0.16 | 0.14 | 0.15 | 0.11 | 0.08 | 0.09 |
| Frequency | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) |
| Bituminous Material (gallon) | | | | | | | | |
| Rate | 3.01 | 6.53 | 4.69 | 4.57 | 3.35 | 2.95 | 2.60 | 3.20 |
| Frequency | (1.00) | (1.00) | (1.00) | (1.00) | (1.00) | (0.82) | (1.00) | (1.00) |
| Bituminous Mixture (ton) | | | | | | | | |
| Rate | 0.02 | 0.40 | 0.00 | 0.00 | 0.13 | 0.23 | 0.34 | 0.16 |
| Frequency | (0.20) | (0.21) | (0.00) | (0.00) | (0.22) | (0.20) | (0.17) | (0.11) |

1. Fiscal Year 1980
2. Rate of material consumption (material units/production unit of activity).
3. Frequency of material use.
4. Not available.

only 51%. The corresponding percentages on the OSHS were 65% in 1980 and 46% in 1983. Similar trends can be observed in the materials use for deep patching activity (No. 202). Furthermore, it can be noted that the rates of consumption of both bituminous materials and conventional hot bituminous mixtures for patching were also reduced during the later years. For example, in 1980 the rate of consumption of hot bituminous mixtures in shallow patching (No. 201) for IS jobs was 1.0 ton per production unit, while in 1983 this rate was dropped by about 40% to 0.61 ton per production unit. Similarly, for the OSHS jobs, the consumption rate was decreased from 0.95 tons in 1980 to 0.61 tons in 1983. In Figures 3.2, 3.3, and 3.4 a graphical presentation of these trends is presented.

Sealing activities (205, 206, and 207) showed different trends. While an increasing rate of consumption of bituminous materials can be noticed for activity 205 (seal coating), a decreasing rate of consumption for the same material is observed for activities 206 and 207 (crack sealing activities). The reason for increase in the use of bituminous materials in seal coating activity (recorded for OSHS jobs only) may be due to the fact that this activity could be considered the principal maintenance activity applied on most of the OSHS, as in the last few years most of resurfacing and rehabilitation work was directed toward the IS. Thus the increase in the use of bituminous materials might have been to compensate for the OSHS repair needs.

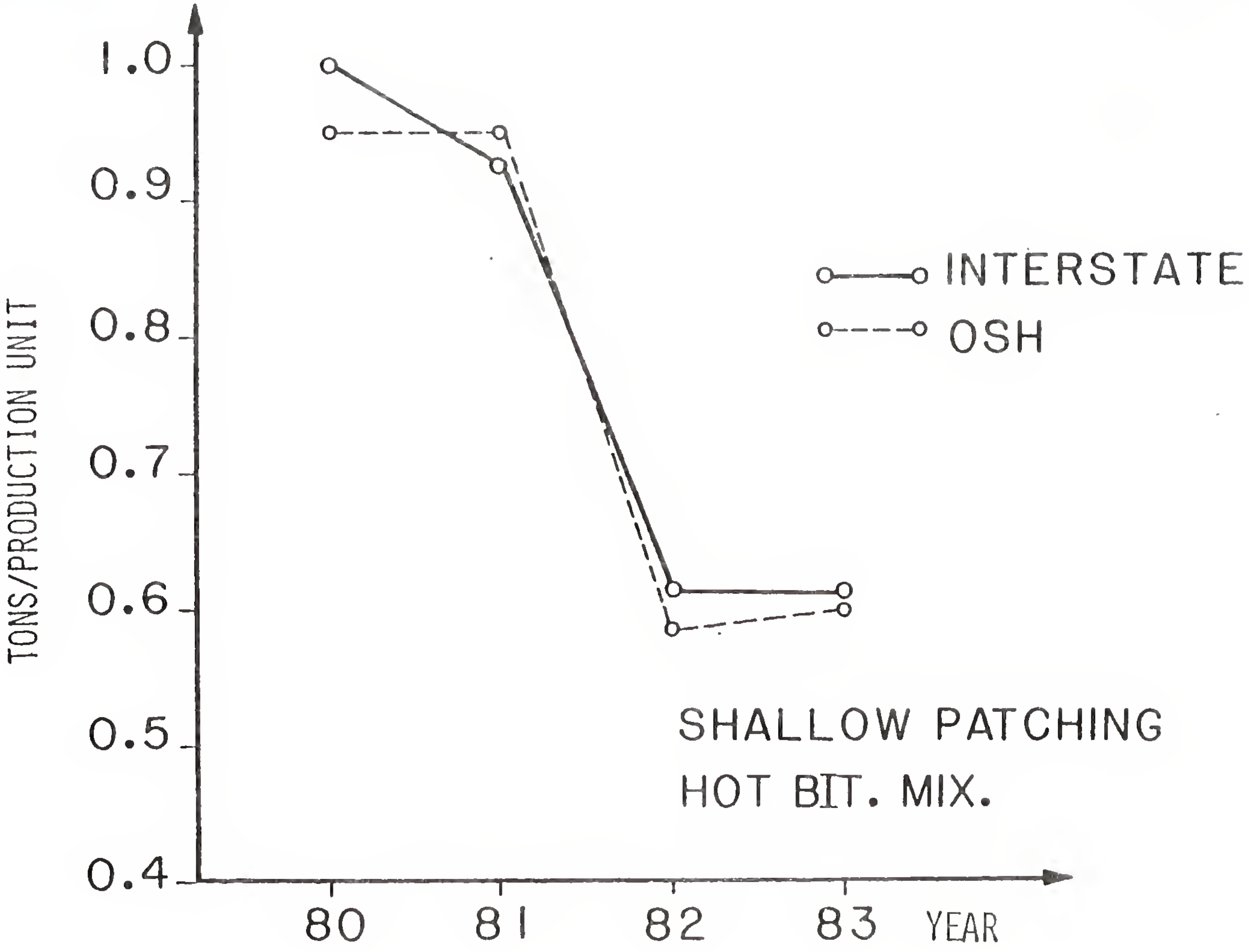

Figure 3.2 Trend in Use of Hot Bituminous Mixtures.

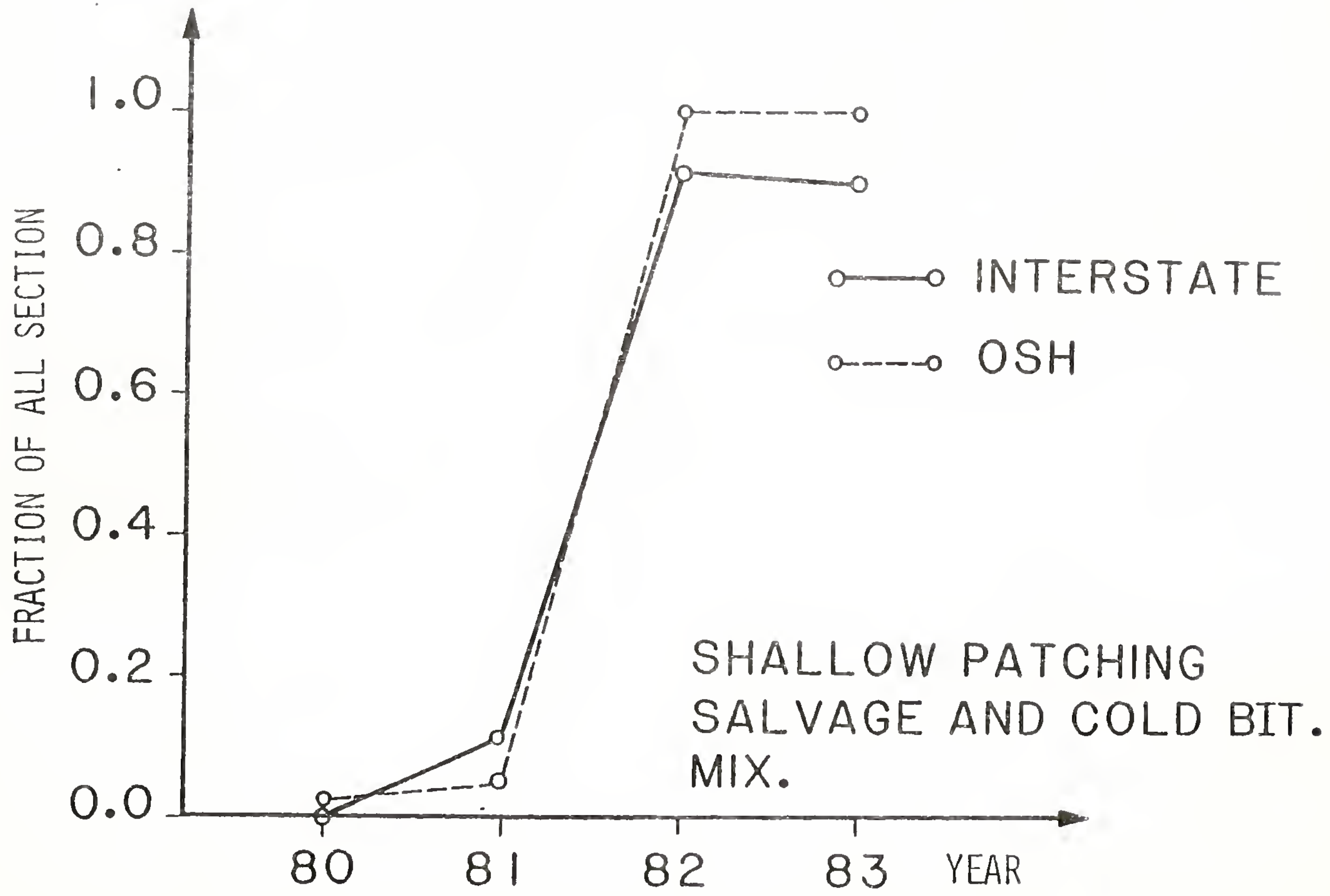

Figure 3.3 Trend in Frequency of Use of Salvage and Cold Bituminous Mixtures.

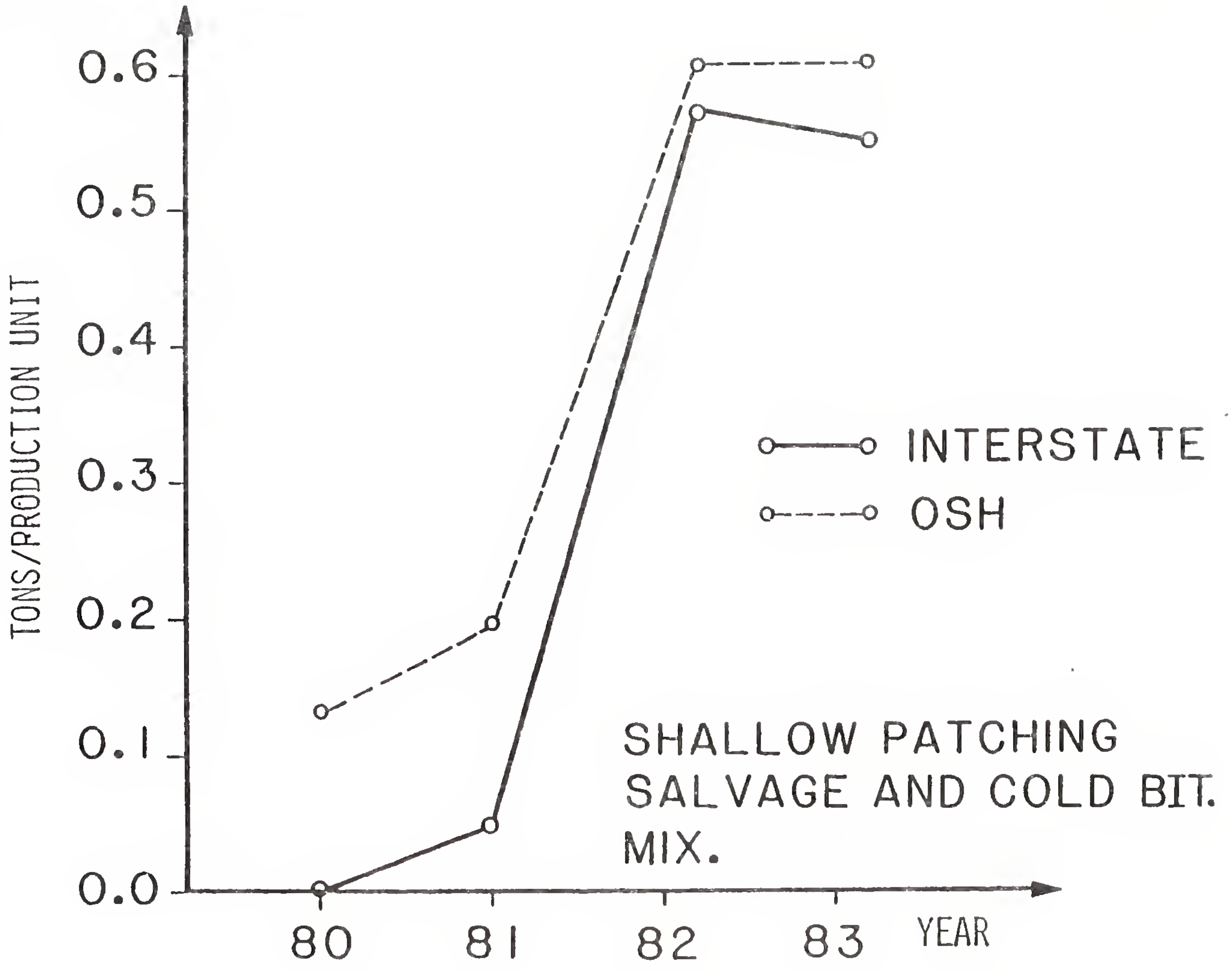

Figure 3.4 Trend in Use of Salvage and Cold Bituminous Mixtures Use.

Finally, it can be noticed from Table 3.4 that the other consumption rates and frequencies indicate a stable trend with only slight variations from year to year.

## 3.5 Trends in Labor and Material Shares of Total Costs

The total costs for different activities presented earlier in Table 3.1 were further broken down into two components: labor and materials. Table 3.4 presents the proportions of total cost assigned to labor and materials for different activity-highway system-fiscal year combinations. For example, 69% of the total cost of activity 201 (shallow patching) on the IS during 1980 was assigned to labor and 31% to materials.

From Table 3.4, it can be noted that in most activities, the share of labor is higher for the IS than that for the OSHS. As mentioned earlier, this could be partially explained by the required additional man-hours to insure safety on jobs of most activities done on the Interstate system.

Generally, it was found that labor share is higher than materials share in all activities except activities 203, 205 and 206.

Finally, it could be seen from Table 3.4 that for all activity-highway system combinations, the shares of labor and materials are stable or subjected to very slight changes from year to year. This may be be explained by the fact that the technology of maintenance practices did not significantly change

Table 3.4 Distribution of Total Cost on Labor and Materials

| Activity No. | Fraction of Total Cost | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Interstate | | | | | | | | Other State Highways | | | | | | | |
| | F.Y. 1980 | | F.Y. 1981 | | F.Y. 1982 | | F.Y. 1983 | | F.Y. 1980 | | F.Y. 1981 | | F.Y. 1982 | | F.Y. 1983 | |
| | Labor | Materials | Labor | Materials | Labor | Materials | Labor | Materials | Labor | Materials | Labor | Materials | Labor | Materials | Labor | Materials |
| 201 | 0.69 | 0.31 | 0.69 | 0.31 | 0.68 | 0.32 | 0.73 | 0.27 | 0.63 | .37 | 0.64 | .36 | 0.63 | .37 | 0.65 | .35 |
| 202 | .64 | .36 | .59 | .41 | .64 | .36 | .61 | .39 | .54 | .46 | .57 | .43 | .57 | .43 | .54 | .46 |
| 203 | .49 | .51 | .55 | .45 | .44 | .56 | .58 | .42 | .36 | .64 | .37 | .63 | .42 | .58 | .36 | .64 |
| 205 | N.A.[1] | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | .15 | .85 | .17 | .83 | .13 | .87 | .13 | .87 |
| 206 | .41 | .59 | .42 | .58 | .43 | .57 | .41 | .59 | .44 | .56 | .44 | .56 | .42 | .58 | .41 | .59 |
| 207 | .63 | .37 | .60 | .40 | .62 | .38 | .61 | .39 | .58 | .42 | .58 | .42 | .57 | .43 | .57 | .43 |
| 209 | .69 | .31 | .72 | .28 | .55 | .45 | .71 | .29 | .69 | .31 | .71 | .29 | .68 | .32 | .69 | .31 |
| 214 | .90 | .10 | .89 | .11 | .87 | .13 | .90 | .10 | .88 | .12 | .88 | .12 | .89 | .11 | .88 | .12 |
| 219 | .73 | .27 | .69 | .31 | .72 | .28 | .73 | .27 | .72 | .28 | .71 | .29 | .66 | .34 | .69 | .31 |

[1] Not available.

in the last few years.

## 3.6 Chapter Summary

The major findings of this part of the analysis can be summarized in the following:

1. The accuracy of pavement maintenance cost estimation depends largely on the accuracy of predicting the cost of patching (shallow and deep) and sealing activities. These two activities constitute more than 85% of the total IS pavement maintenance costs and more than 65% of the total OSHS pavement maintenance costs.

2. The single activity which contributed most to the total pavement maintenance costs is shallow patching activity, where about 30% to 40% of the total pavement maintenance expenditures are spent.

3. There is a significant difference in the use of labor and materials for the same pavement maintenance activities applied to IS and OSHS. This is because maintenance practices are different for these two systems. In addition, the maintenance needs of these two systems are also very different. Consequently, the prediction of pavement maintenance costs should be undertaken separately for these two systems.

4. The consumption rates and frequencies of use of materials in

patching and sealing activities have been subjected to significant change over the last four years, particularly for bituminous materials and mixtures. On the other hand, labor consumption rates have remained generally stable over the same period (1980-83).

# CHAPTER 4

# DISAGGREGATE ANALYSIS OF PAVEMENT ROUTINE MAINTENANCE

## 4.1 Introduction

In Chapter 3, the state highway system of Indiana was divided into two groups: Interstate and Other State Highways. This classification is currently used by the Maintenance Division of the IDOH. In this Chapter a further disaggregation of the highway system will be considered. In addition to the system type (Interstate, and Other State Highway), the climatic zone and pavement type will be included. The maintenance expenditure will be analyzed by highway type, by climatic zone and by pavement type. Such disaggregate analysis would add insight in to the effect of climate and pavement type on maintenance needs.

## 4.2 Climatic Zones

As indicated in Chapter 2, the State of Indiana can be divided into three climatic zones, as shown in Figure 2.5. The northern zone was found to have a regional factor of 1.5, and the central and southern zones have regional factors of 1.1 and 1.0, respectively (5). Further investigation of the data indicated that the central and southern zones could be combined into one zone without losing any information. Thus, it was decided to consider only two climatic zones, the northern zone and the southern zone covering the central and southern zones in Figure 5.5.

## 4.3 Pavement Types

Three major pavement types were considered: flexible pavement, rigid pavement, and resurfaced pavement. It was found that there is a significant variation in the distribution of pavement types by highway system and climatic zone combination. The distribution of lane-miles of different pavement types is shown in Table 4.1. It is clear that flexible and resurfaced pavements are the dominant types in the OSH system (87% of the total lane-miles of the OSH system). On the other hand, rigid pavement is the principal type in the Interstate system (67% of the total Interstate lane-miles), followed by resurfaced pavement (25% of total Interstate lane-miles).

## 4.4 Developing Pavement Maintenance Rates

The "Breakdown" routine from the Statistical Package for Social Sciences, SPSS (55) was used to develop pavement maintenance rates in terms of dollars per lane-mile and production units per lane-mile. These rates were developed from highway sections that have only one pavement type throughout the entire length. That is, sections with more than one pavement type (e.g. partially resurfaced) were excluded from the calculation of maintenance rates.

Table 4.1 Distribution of Lane-Miles By Pavement Type.

| Pavement Type | Percent of Total Lane-Miles in | | | |
|---|---|---|---|---|
| | Interstate | | Other State Highway | |
| | North | South | North | South |
| Flexible | 0 | 1.0 | 11.8 | 27.4 |
| Rigid | 2.1 | 7.2 | 3.7 | 7.3 |
| Resurfaced | 0.7 | 2.8 | 12.3 | 23.7 |
| Total | 2.8 | 11.0 | 27.8 | 58.4 |
| | 13.8 | | 86.2 | |

Note: Data shown is as of 1983.

Flexible pavement maintenance rates for Interstate system for each of the four fiscal years, for each activity, and for both the northern and southern zones are summarized in Table 4.2. Similar maintenance rates for the Interstate rigid pavement sections, Interstate resurfaced pavement sections, OSH flexible pavement sections, OSH rigid pavement sections and OSH resurfaced pavement sections are given in Table 4.3 through 4.7, respectively.

### 4.4.1 Analysis of Total Pavement Maintenance Expenditures

Total maintenance expenditures presented in Tables 4.2 to 4.7 are graphically depicted in Figure 4.1. From the Figure, it is clear that there is a trend of higher maintenance costs in the OSH system than in the Interstate system, as was indicated earlier in Chapter 3. On the other hand, the average pavement maintenance costs in the northern zone is higher than that in the southern zone. This may be related to the effect of the relatively harsher winter weather of the northern zone. The degree of the difference in maintenance expenditure between the northern and southern zones varies with pavement type and the highway system. While the difference is significant in OSH resurfaced pavement it is unnoticeable in case of OSH flexible pavement. On the other hand, a moderate difference exists for the Interstate system. Finally, the effect of pavement type could be noticed particularly when rigid pavement is com-

Table 4.2 Breakdown of Pavement Maintenance Rates of Interstate Flexible Pavement

| Activity | 1980 | | 1981 | | 1982 | | 1983 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | North | South | North | South | North | South | North | South | North | South |
| 201 | | | | | | | | | | |
| $/LM[1] | N.A. | 6.46 | N.A. | 1.49 | N.A. | 45.44 | N.A. | 25.30 | N.A. | 19.68 |
| P.U./LM[2] | N.A. | 0.052 | N.A. | 0.012 | | 0.378 | | 0.180 | | 0.155 |
| 202 | | | | | | | | | | |
| $/LM | N.A. | 0.00 | N.A. | 3.89 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.97 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.033 | | 0.00 | | 0.00 | | 0.008 |
| 203 | | | | | | | | | | |
| $/LM | N.A. | 0.00 | N.A. | 9.76 | N.A. | 27.58 | N.A. | 0.00 | N.A. | 9.34 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.248 | | 0.619 | | 0.00 | | 0.217 |
| 205 | | | | | | | | | | |
| $/LM | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.00 | | 0.00 | | 0.00 | | 0.00 |
| 206 | | | | | | | | | | |
| $/LM | N.A. | 35.55 | N.A. | 25.84 | N.A. | 6.65 | N.A. | 26.64 | N.A. | 23.67 |
| P.U./LM | N.A. | 0.269 | N.A. | 0.244 | | 0.065 | | 0.171 | | 0.19 |
| 207 | | | | | | | | | | |
| $/LM | N.A. | 69.78 | N.A. | 92.01 | N.A. | 41.47 | N.A. | 58.10 | N.A. | 65.34 |
| P.U./LM | N.A. | 0.233 | N.A. | 0.532 | | 0.218 | | 0.259 | | 0.31 |
| 209 | | | | | | | | | | |
| $/LM | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.00 | | 0.00 | | 0.00 | | 0.00 |
| 214 | | | | | | | | | | |
| $/LM | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.00 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.00 | | 0.00 | | 0.00 | | 0.00 |
| 219 | | | | | | | | | | |
| $/LM | N.A. | 3.43 | N.A. | 47.19 | N.A. | 55.01 | N.A. | 24.53 | N.A. | 32.50 |
| P.U./LM | N.A. | 0.327 | N.A. | 4.160 | N.A. | 3.95 | | 2.048 | | 2.62 |
| Total $/LM | N.A. | 115.24 | N.A. | 180.18 | N.A. | 176.17 | N.A. | 134.57 | N.A. | 151.25 |
| No. of Sections | | | | | | | | | N.A. | 5 |
| Lane Miles | | | | | | | | | N.A. | 252.60 |
| Average age | | | | | | | | | N.A. | 6 |
| Average Accumulated ADT | | | | | | | | | N.A. | 20.4 $\times 10^6$ |
| Average Accumulated EAL | | | | | | | | | N.A. | 3.4 $\times 10^6$ |

1 Dollars/Lane-Mile

2 Production Units/Lane-Mile

Table 4.3 Breakdown of Pavement Maintenance Rates of Interstate Rigid Pavement

| Activity | 1980 | | 1981 | | 1982 | | 1983 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | North | South | North | South | North | South | North | South | North | South |
| 201 $/LM[1] | 57.87 | 50.76 | 86.55 | 80.68 | 95.17 | 87.09 | 130.39 | 95.22 | 92.50 | 78.44 |
| P.U./LM[2] | 0.33 | 0.45 | 0.63 | 0.63 | 0.83 | 0.73 | 1.12 | 0.74 | 0.73 | 0.64 |
| 202 $/LM | 25.96 | 15.89 | 28.02 | 26.74 | 47.55 | 26.07 | 33.24 | 12.68 | 33.69 | 18.24 |
| P.U./LM | 0.33 | 0.13 | 0.27 | 0.28 | 0.61 | 0.21 | 0.44 | 0.48 | 0.41 | 0.28 |
| 203 $/LM | 00.00 | 8.19 | 8.22 | 9.46 | 9.03 | 13.36 | 2.64 | 0.60 | 4.97 | 7.903 |
| P.U./LM | 0.00 | 0.16 | 0.20 | 0.15 | 0.15 | 0.25 | 0.04 | 0.01 | 0.10 | 0.14 |
| 205 $/LM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| P.U./LM | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 206 $/LM | 40.99 | 37.46 | 99.79 | 81.61 | 23.94 | 27.92 | 22.13 | 47.06 | 46.71 | 48.51 |
| P.U./LM | 0.33 | 0.24 | 0.85 | 0.53 | 0.27 | 0.22 | 0.20 | 0.40 | 0.41 | 0.35 |
| 207 $/LM | 47.39 | 12.03 | 73.64 | 36.61 | 65.71 | 15.20 | 23.95 | 25.03 | 52.54 | 22.22 |
| P.U./LM | 0.37 | 0.10 | 0.41 | 0.12 | 0.26 | 0.07 | 0.09 | 0.08 | 0.28 | 0.09 |
| 209 $/LM | 9.09 | 8.46 | 7.53 | 1.76 | 0.00 | 5.94 | 5.60 | 1.59 | 5.55 | 4.44 |
| P.U./LM | 2.22 | 1.91 | 0.92 | 0.52 | 0.00 | 1.01 | 0.79 | 0.78 | 0.98 | 1.06 |
| 214 $/LM | 18.49 | 3.182 | 12.73 | 6.87 | 84.62 | 1.45 | 29.01 | 7.79 | 36.21 | 4.82 |
| P.U./LM | 0.34 | 0.09 | 0.33 | 0.27 | 0.20 | 0.08 | 0.83 | 0.34 | 0.43 | 0.20 |
| 219 $/LM | 8.81 | 9.27 | 10.89 | 11.19 | 14.32 | 8.43 | 4.97 | 14.75 | 11.00 | 11.05 |
| P.U./LM | 0.93 | 1.29 | 1.47 | 1.29 | 1.19 | 1.13 | 1.11 | 1.68 | 1.18 | 1.35 |
| Total $/LM | 208.60 | 145.25 | 327.39 | 254.93 | 339.79 | 185.95 | 256.93 | 239.34 | 283.18 | 206.37 |
| No. of Sections | | | | | | | | | 5 | 21 |
| Lane Miles | | | | | | | | | 424.8 | 1526.13 |
| Average age | | | | | | | | | 14 | 16 |
| Average Accumulated ADT | | | | | | | | | $144\times10^6$ | $111\times10^6$ |
| Average Accumulated EAL | | | | | | | | | $24.2\times10^6$ | $20.5\times10^6$ |

1 Dollars/Lane-Mile

2 Production Units/Lane-Mile

Table 4.4 Breakdown of Pavement Maintenance Rates of Interstate Resurfaced Pavement

| Activity | 1980 | | 1981 | | 1982 | | 1983 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | North | South | North | South | North | South | North | South | North | South |
| 201<br>$/LM[1]<br>P.U./LM[2] | 41.84<br>0.32 | 44.82<br>0.37 | 74.53<br>0.57 | 32.22<br>0.31 | 125.29<br>1.17 | 27.84<br>0.29 | 65.06<br>0.62 | 26.43<br>0.24 | 76.68<br>0.67 | 32.83<br>0.30 |
| 202<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 23.28<br>0.34 | 56.66<br>0.45 | 21.76<br>0.22 | 16.48<br>0.10 | 1.96<br>0.02 | 0.00<br>0.00 | 12.68<br>0.14 | 33.69<br>0.14 | 14.92<br>0.18 |
| 203<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 1.22<br>0.01 | 10.04<br>0.10 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 2.51<br>0.03 | 0.31<br>.003 |
| 205<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 |
| 206<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 12.61<br>0.11 | 0.00<br>0.00 | 52.35<br>0.32 | 0.00<br>0.00 | 8.14<br>0.06 | 0.00<br>0.00 | 0.77<br>0.004 | 0.00<br>0.00 | 23.67<br>0.12 |
| 207<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 35.09<br>0.30 | 24.69<br>0.1 | 64.95<br>0.34 | 0.00<br>0.00 | 8.73<br>0.06 | 40.<br>0.31 | 51.<br>0.27 | 16.17<br>0.10 | 39.95<br>0.24 |
| 209<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 0.00<br>0.00 | 0.00<br>0.00 | 36.63<br>5.3 | 0.00<br>0.00 | 15.11<br>2.54 | 0.00<br>0.00 | 3.03<br>0.60 | 0.00<br>0.00 | 13.69<br>2.11 |
| 214<br>$/LM<br>P.U./LM | 5.18<br>0.08 | 0.00<br>0.00 | 1.83<br>0.04 | 0.00<br>0.00 | 2.05<br>0.06 | 0.35<br>0.01 | 38.90<br>0.87 | 1.63<br>0.05 | 11.99<br>0.27 | 0.50<br>.02 |
| 219<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 13.77<br>0.96 | 12.81<br>2.00 | 0.00<br>0.00 | 2.44<br>0.32 | 4.66<br>0.38 | 3.50<br>0.54 | 1.94<br>0.20 | 4.69<br>0.72 | 5.09<br>0.39 |
| Total $/LM | 47.01 | 130.78 | 180.56 | 207.92 | 146.2 | 66.79 | 147.46 | 97.52 | 130.31 | 125.75 |
| No. of Sections | | | | | | | | | 2 | 6 |
| Lane Miles | | | | | | | | | 62.00 | 366.99 |
| Average age | | | | | | | | | 3 | 3 |
| Average Accumulated ADT | | | | | | | | | $76.3 \times 10^6$ | $29.9 \times 10^6$ |
| Average Accumulated EAL | | | | | | | | | $5.34 \times 10^6$ | $3.77 \times 10^6$ |

[1] Dollars/Lane-Mile

[2] Production Units/Lane-Mile

Table 4.5 Breakdown of Pavement Maintenance Rates of OSH Flexible Pavement

| Activity | 1980 |  | 1981 |  | 1982 |  | 1983 |  | Average |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | North | South | North | South | North | South | North | South | North | South |
| 201 |  |  |  |  |  |  |  |  |  |  |
| $/LM[1] | 136.41 | 116.12 | 141.94 | 73.10 | 182.07 | 83.73 | 157.25 | 61.99 | 154.42 | 83.74 |
| P.U./LM[2] | 1.25 | 1.43 | 1.13 | 0.82 | 1.88 | 0.93 | 1.45 | 0.66 | 1.43 | 0.96 |
| 202 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 8.57 | 18.94 | 19.64 | 15.04 | 11.99 | 25.07 | 8.01 | 16.43 | 12.05 | 18.88 |
| P.U./LM | 0.15 | 0.27 | 0.16 | 0.19 | 0.11 | 0.38 | 0.10 | 0.19 | 0.13 | 0.26 |
| 203 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 73.16 | 61.01 | 35.33 | 75.61 | 5.86 | 34.64 | 7.88 | 24.73 | 30.56 | 48.99 |
| P.U./LM | 1.74 | 1.71 | 1.00 | 2.07 | 0.12 | 0.84 | 0.20 | 0.59 | 0.77 | 1.30 |
| 205 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 79.14 | 119.61 | 0.48 | 86.01 | 85.64 | 106.79 | 203.33 | 71.41 | 92.15 | 95.98 |
| P.U./LM | 0.04 | 0.07 | 0.005 | 0.06 | 0.05 | 0.08 | 0.10 | 0.06 | 0.05 | .07 |
| 206 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 7.78 | 0.18 | 2.81 | 1.00 | 7.51 | 1.85 | 2.70 | 1.96 | 5.20 | 1.25 |
| P.U./LM | 0.03 | 0.001 | 0.02 | 0.01 | 0.03 | 0.13 | 0.02 | 0.01 | 0.03 | .04 |
| 207 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 30.14 | 85.65 | 40.38 | 56.21 | 48.68 | 66.62 | 55.68 | 81.06 | 43.73 | 72.39 |
| P.U./LM | 0.09 | 0.28 | 0.13 | 0.23 | 0.19 | 0.25 | 0.13 | 0.32 | 0.14 | 0.27 |
| 209 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 1.02 | 0.58 | 0.19 | 0.59 | 0.00 | 4.61 | 0.89 | 0.61 | 0.52 | 1.60 |
| P.U./LM | 0.18 | 0.14 | 0.07 | 0.15 | 0.00 | 1.94 | 0.13 | 0.25 | 0.10 | 0.62 |
| 214 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 0.14 | 0.46 | 0.35 | 0.67 | 0.92 | 0.00 | 0.31 | 0.65 | 0.42 | 0.44 |
| P.U./LM | 0.004 | 0.02 | 0.09 | 0.03 | 0.03 | 0.00 | 0.007 | 0.02 | 0.03 | 0.02 |
| 219 |  |  |  |  |  |  |  |  |  |  |
| $/LM | 1.38 | 5.22 | 4.10 | 3.97 | 5.08 | 14.24 | 17.33 | 7.02 | 6.98 | 7.61 |
| P.U./LM | 0.17 | 0.35 | 0.40 | 0.34 | 0.35 | 0.68 | 2.18 | 0.40 | 0.78 | 0.44 |
| Total $/LM | 337.71 | 407.78 | 245.22 | 312.32 | 347.75 | 337.57 | 452.15 | 265.86 | 346.02 | 330.88 |
| No. of Sections |  |  |  |  |  |  |  |  | 57 | 156 |
| Lane Miles |  |  |  |  |  |  |  |  | 1437.8 | 3865.13 |
| Average age |  |  |  |  |  |  |  |  | 13 | 9 |
| Average Accumulated ADT |  |  |  |  |  |  |  |  | $5.57 \times 10^6$ | $7.42 \times 10^6$ |
| Average Accumulated EAL |  |  |  |  |  |  |  |  | $0.36 \times 10^6$ | $0.34 \times 10^6$ |

[1] Dollars/Lane-Mile

[2] Production Units/Lane-Mile

Table 4.6 Breakdown of Pavement Maintenance Rates of OSH Rigid Pavement

| Activity | 1980 |  | 1981 |  | 1982 |  | 1983 |  | Average |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | North | South | North | South | North | South | North | South | North | South |
| 201<br>$/LM[1] | N.A. | 50.57 | N.A. | 101.14 | N.A. | 192.21 | N.A. | 57.59 | N.A. | 100.38 |
| P.U./LM[2] | N.A. | 0.48 | N.A. | 1.10 | N.A. | 2.05 | N.A. | 0.52 | N.A. | 1.04 |
| 202<br>$/LM | N.A. | 16.32 | N.A. | 64.56 | N.A. | 13.17 | N.A. | 13.08 | N.A. | 26.79 |
| P.U./LM | N.A. | 0.16 | N.A. | 0.62 | N.A. | 0.09 | N.A. | 0.15 | N.A. | 0.26 |
| 203<br>$/LM | N.A. | 10.79 | N.A. | 0.00 | N.A. | 13.56 | N.A. | 0.00 | N.A. | 6.09 |
| P.U./LM | N.A. | 0.24 | N.A. | 0.00 | N.A. | 0.10 | N.A. | 0.00 | N.A. | 0.09 |
| 205<br>$/LM | N.A. | 0.00 | N.A. | 59.15 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 14.79 |
| P.U./LM | N.A. | 0.24 | N.A. | 0.07 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.02 |
| 206<br>$/LM | N.A. | 64.22 | N.A. | 28.61 | N.A. | 24.62 | N.A. | 64.95 | N.A. | 45.60 |
| P.U./LM | N.A. | 0.27 | N.A. | 0.11 | N.A. | 0.13 | N.A. | 0.28 | N.A. | 0.20 |
| 207<br>$/LM | N.A. | 49.17 | N.A. | 51.31 | N.A. | 166.05 | N.A. | 38.80 | N.A. | 76.33 |
| P.U./LM | N.A. | 0.16 | N.A. | 0.19 | N.A. | 0.54 | N.A. | 0.14 | N.A. | 0.26 |
| 209<br>$/LM | N.A. | 0.00 | N.A. | 4.34 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 1.08 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.76 | N.A. | 0.00 | N.A. | 0.00 | N.A. | 0.19 |
| 214<br>$/LM | N.A. | 0.00 | N.A. | 8.83 | N.A. | 0.00 | N.A. | 0.51 | N.A. | 2.34 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.31 | N.A. | 0.00 | N.A. | 0.03 | N.A. | .09 |
| 219<br>$/LM | N.A. | 0.00 | N.A. | 4.94 | N.A. | 1.29 | N.A. | 10.03 | N.A. | 4.07 |
| P.U./LM | N.A. | 0.00 | N.A. | 0.60 | N.A. | 0.13 | N.A. | 0.71 | N.A. | 0.36 |
| Total $/LM | N.A. | 191.07 | N.A. | 322.89 | N.A. | 410.92 | N.A. | 184.95 | N.A. | 277.46 |
| No. of Sections |  |  |  |  |  |  |  |  | N.A. | 6 |
| Lane Miles |  |  |  |  |  |  |  |  | N.A. | 137.18 |
| Average age |  |  |  |  |  |  |  |  | N.A. | 15 |
| Average Accumulated ADT |  |  |  |  |  |  |  |  | N.A. | $88.3 \times 10^{6}$ |
| Average Accumulated EAL |  |  |  |  |  |  |  |  | N.A. | $4.00 \times 10^{6}$ |

[1] Dollars/Lane-Mile

[2] Production Units/Lane-Mile

Table 4.7 Breakdown of Pavement Maintenance Rates of OSH Resurfaced Pavement

| Activity | 1980 | | 1981 | | 1982 | | 1983 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | North | South | North | South | North | South | North | South | North | South |
| 201<br>$/LM[1]<br>P.U./LM[2] | 173.14<br>1.71 | 84.88<br>0.98 | 134.50<br>1.55 | 53.20<br>0.51 | 216.69<br>2.85 | 94.93<br>0.93 | 140.55<br>1.63 | 59.92<br>0.57 | 166.22<br>1.94 | 73.23<br>0.75 |
| 202<br>$/LM<br>P.U./LM | 40.86<br>0.61 | 15.91<br>0.23 | 17.22<br>0.23 | 15.27<br>0.19 | 15.82<br>0.16 | 11.88<br>0.15 | 9.02<br>0.15 | 9.91<br>0.13 | 20.73<br>0.29 | 13.24<br>0.18 |
| 203<br>$/LM<br>P.U./LM | 0.77<br>0.01 | 4.41<br>0.12 | 4.22<br>0.10 | 1.93<br>0.04 | 6.89<br>0.12 | 7.09<br>0.17 | 58.87<br>0.50 | 1.18<br>0.02 | 17.69<br>0.18 | 3.65<br>.09 |
| 205<br>$/LM<br>P.U./LM | 0.00<br>0.00 | 67.83<br>0.06 | 0.00<br>0.00 | 8.60<br>0.01 | 33.23<br>0.04 | 3.09<br>0.004 | 58.70<br>0.05 | 3.60<br>0.004 | 22.98<br>0.02 | 20.78<br>.02 |
| 206<br>$/LM<br>P.U./LM | 8.16<br>0.07 | 7.25<br>0.06 | 21.41<br>0.18 | 3.78<br>0.05 | 13.88<br>0.17 | 10.47<br>0.11 | 12.72<br>0.13 | 8.79<br>0.09 | 14.04<br>0.14 | 7.57<br>.08 |
| 207<br>$/LM<br>P.U./LM | 102.49<br>0.37 | 97.5<br>0.39 | 90.67<br>0.28 | 108.21<br>0.40 | 82.05<br>0.32 | 75.60<br>0.24 | 84.23<br>0.24 | 104.20<br>0.42 | 89.86<br>0.30 | 96.38<br>0.36 |
| 209<br>$/LM<br>P.U./LM | 3.29<br>0.66 | 10.98<br>2.52 | 8.53<br>1.61 | 16.27<br>3.05 | 7.38<br>1.23 | 8.37<br>2.15 | 11.15<br>1.73 | 4.24<br>1.03 | 7.59<br>1.31 | 9.97<br>2.19 |
| 214<br>$/LM<br>P.U./LM | 15.09<br>0.50 | 14.24<br>0.52 | 18.04<br>0.59 | 16.52<br>0.71 | 17.97<br>0.75 | 24.41<br>1.23 | 15.92<br>1.08 | 13.56<br>0.49 | 16.76<br>0.73 | 17.18<br>0.74 |
| 219<br>$/LM<br>P.U./LM | 16.42<br>2.14 | 23.30<br>0.56 | 19.97<br>1.65 | 8.26<br>0.98 | 14.00<br>1.15 | 11.37<br>1.11 | 5.55<br>0.54 | 11.45<br>0.56 | 13.98<br>1.37 | 13.59<br>0.80 |
| Total $/LM | 360.22 | 326.32 | 314.57 | 232.04 | 407.90 | 247.20 | 396.71 | 216.85 | 369.85 | 255.60 |
| No. of Sections | | | | | | | | | 27 | 57 |
| Lane Miles | | | | | | | | | 1061.5 | 2227.6 |
| Average age | | | | | | | | | 7 | 7 |
| Average Accumulated ADT | | | | | | | | | $16.73\times10^6$ | $14.80\times10^6$ |
| Average Accumulated EAL | | | | | | | | | $0.71\times10^6$ | $0.63\times10^6$ |

[1] Dollars/Lane-Mile

[2] Production Units/Lane-Mile

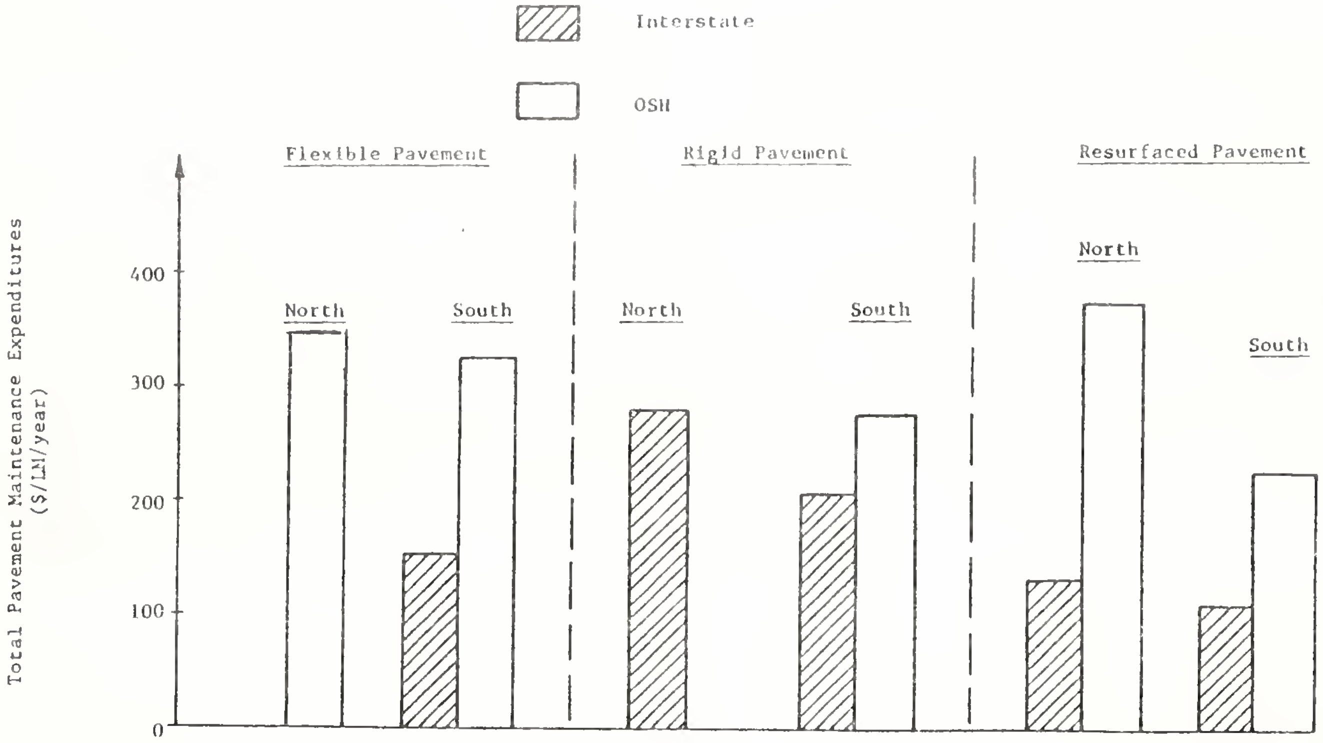

Figure 4.1 Breakdown of Total Pavement Maintenance Expenditure

pared with the resurfaced rigid pavement. A considerable difference could be seen for the Interstate system, while a moderate difference exists for the OSH system. This can be explained by considering the average ages of the pavement sections.

For example, the average age of Interstate unresurfaced rigid pavement sections is about 15 years, while the average age of the Interstate resurfaced rigid pavement sections is about 3 years. This considerable difference in age and consequently in accumulated EAL as shown in Tables 4.2 through 4.7 may have caused the significant difference between the maintenance expenditures in Interstate resurfaced and unresurfaced rigid pavements. On the other hand, while the average age of the OSH unresurfaced rigid pavements is 15 years, the corresponding age of the resurfaced pavements is 7 years. Relatively older resurfaced pavements may have caused the moderate difference in expenditure between the resurfaced and the unresurfaced pavements of the OSH system.

### 4.4.2 Analysis of Total Expenditure Distribution on Pavement Maintenance Activities

Nine pavement maintenance activities listed in Table 2.9 were combined into three major groups: (i) patching group which consists of shallow patching (activity 201), deep patching (activity 202), and premix leveling (activity 203); (ii) sealing group which consists of seal coating (activity 205), sealing longitudinal cracks and joints (activity 206), and sealing cracks (activity 207); and (iii) other activities group which consists of cutting relief joints (activity 209), joint and bump buring (activity 214), and others (activity 219). To present the relative contribution of each group to the total pavement maintenance expenditure, the percent of total expenditure allocated to each group for each of the four fiscal years for each pavement type, highway system and climatic zone combination was calculated from Tables 4.2 through 4.7. Figure 4.2 summarizes these results.

The first implication of the results is that regardless of pavement type, highway system or location, the portion of total expenditure allocated to patching and sealing groups is considerably large. For example, this portion was found to be as high as 95% to 100% of the total expenditure, as may be seen in several cases in Figure 4.2. Thus, an accurate estimate of patching and sealing needs will definitely lead to an overall accurate estimate of the total pavement maintenance needs.

On the other hand, the relative portions of patching and sealing differ from location to location. It is obvious in almost all cases shown in Figure 4.2 that there is a tendency toward higher level of patching in the northern part than in the southern part while the sealing level in the south tend to be higher than that of the north. This trend

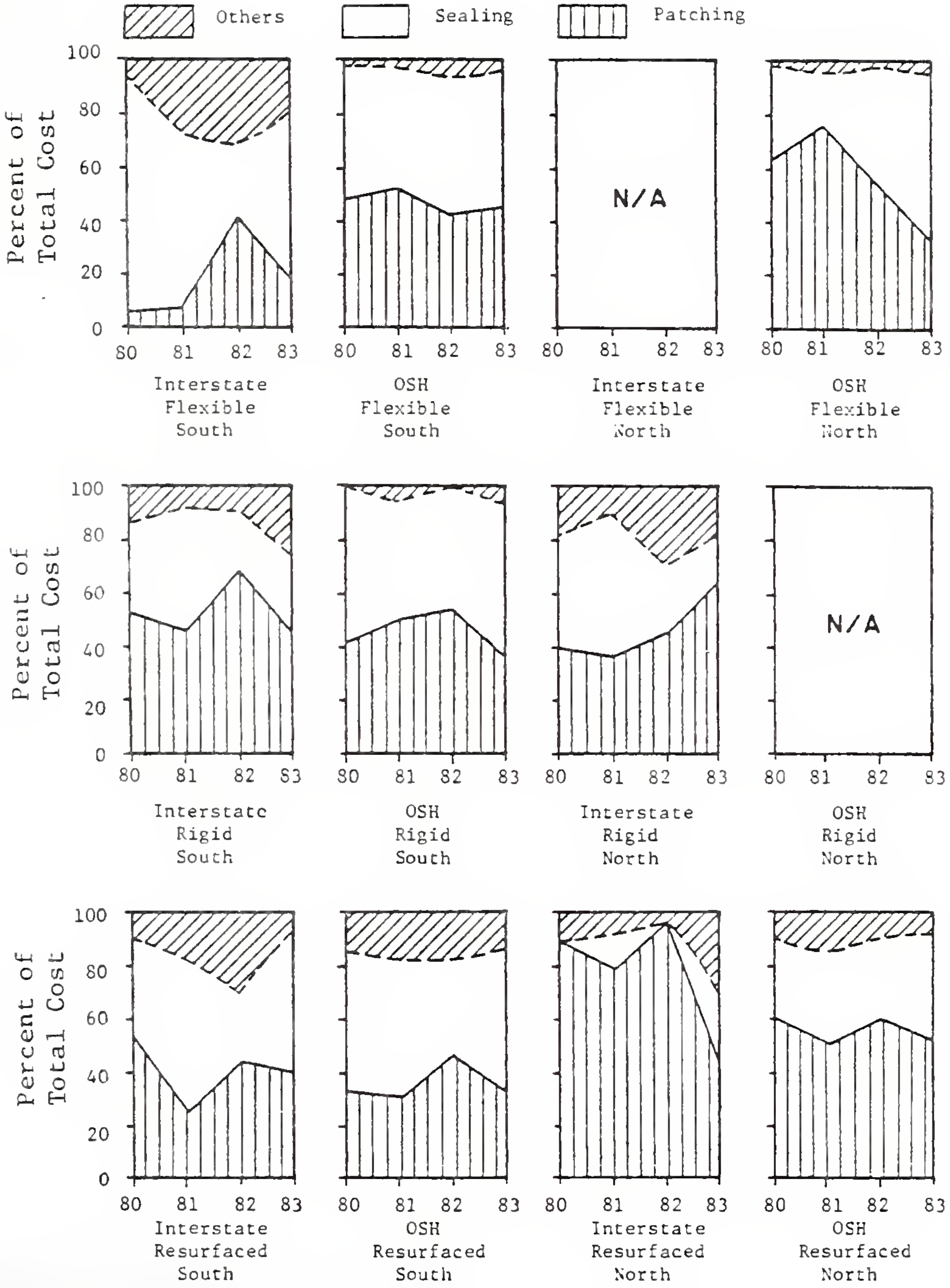

Figure 4.2 Distribution of Total Pavement Maintenance Expenditure by Maintenance Group

may be explained as follows. The relatively mild weather in the southern part of the state allows more time for sealing jobs to be undertaken in fall. Increased sealing activity reduces the need for patching jobs that are generally performed in the following spring. Sealing acts as preventive maintenance which reduces the amount of potholes that takes place during the spring. Moreover, the mild weather of the southern zone produces, in general, less potholes than in the north. On the other hand, harsher winter and less time for preventive maintenance (sealing) cause more potholes in the northern zone which in turn require more patching jobs.

Finally, it can be seen from Tables 4.2 to 4.7 that the principal component of the patching group is shallow patching (activity 201) and of the sealing group is crack sealing (activity 207). For example, shallow patching expenditure is about 60% to 80% of the total patching expenditure, and crack sealing is about 40% to 50% of the total sealing expenditure. This indicates that these two activities can be effectively used as control items and prediction of the two activities can lead to an overall effective prediction of patching and sealing expenditures.

## 4.5 Other Information

Other data, such as average age, average accumulated ADT, and average accumulated EAL for each highway system, pavement type and location, are also included in Tables 4.2

to 4.7. Generally, the average ages of Interstate pavement sections are less than those of OSH sections. For example, while the average age of Interstate flexible pavements is about 7 years, the corresponding age of the OSH system is 11 years. Similarly, for the resurfaced pavements, the average ages for the Interstate and OSH systems are 3 and 7 years, respectively. The later age comparison emphasizes the fact that most of the resurfacing projects in recent years took place in the Interstate system.

An useful parameter to analyze routine maintenance costs by pavement type is the average level of traffic represented by accumulated EAL. Figures 4.3 and 4.4 are graphical presentations of accumulated EAL values included in Tables 4.2 to 4.7 for the Interstate and OSH systems, respectively. First, it can be observed from Figures 4.3 and 4.4 that there is a difference in the traffic level between the Interstate and OSH systems. For example, the average traffic level (accumulated EAL) on flexible pavement sections in the southern zone of the Interstate system is about 10 times that of the OSH system. This difference in EAL is due to the higher ADT and higher percent of trucks on the Interstate system than on the OSH.

Secondly, it is obvious from Figures 4.3 and 4.4 that there is a consistent difference between the traffic level in the northern zone and southern part, with a higher level in the northern zone. This can be referred again to the

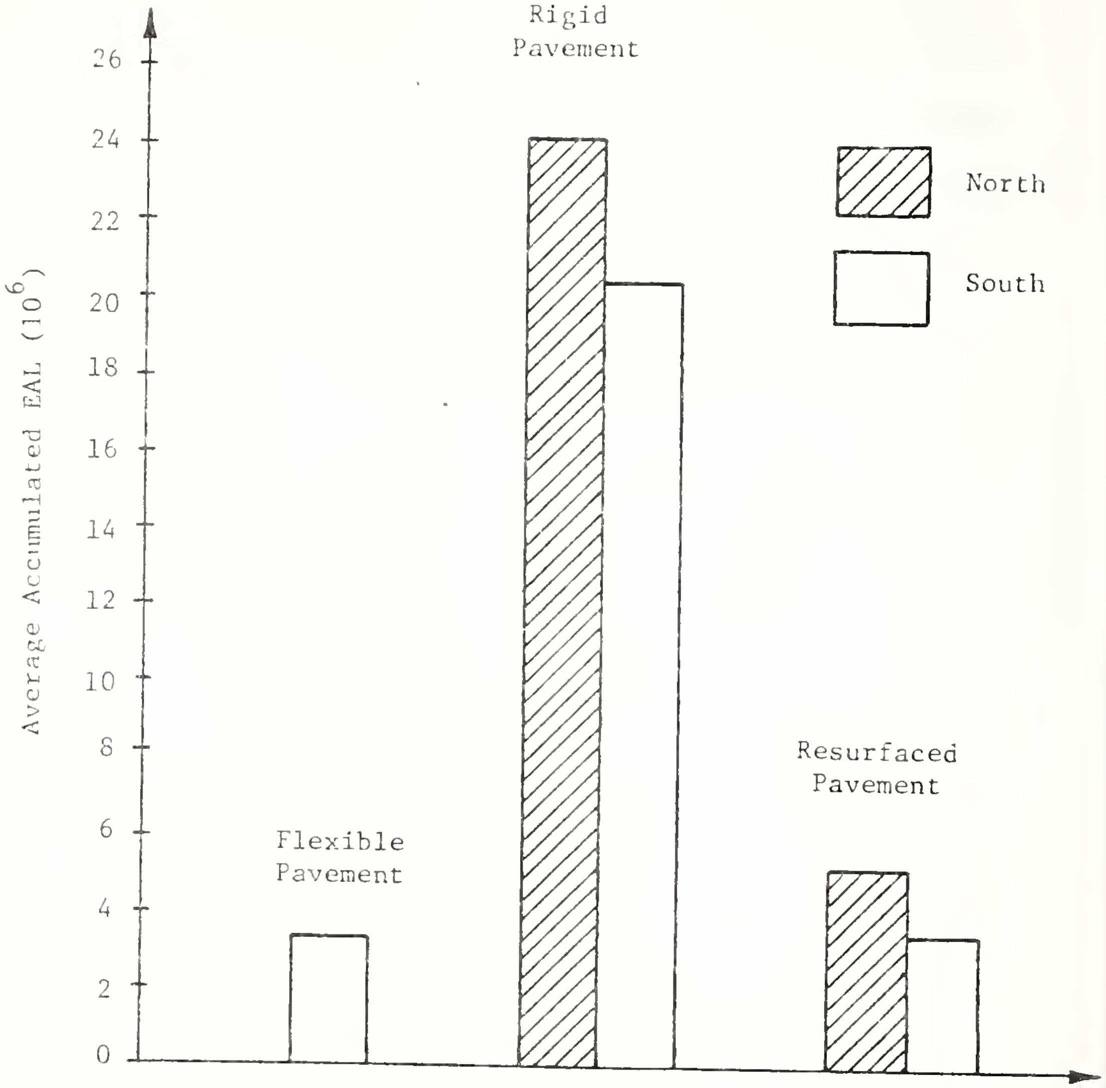

Figure 4.3 Average Accumulated EAL Values On the Interstate System.

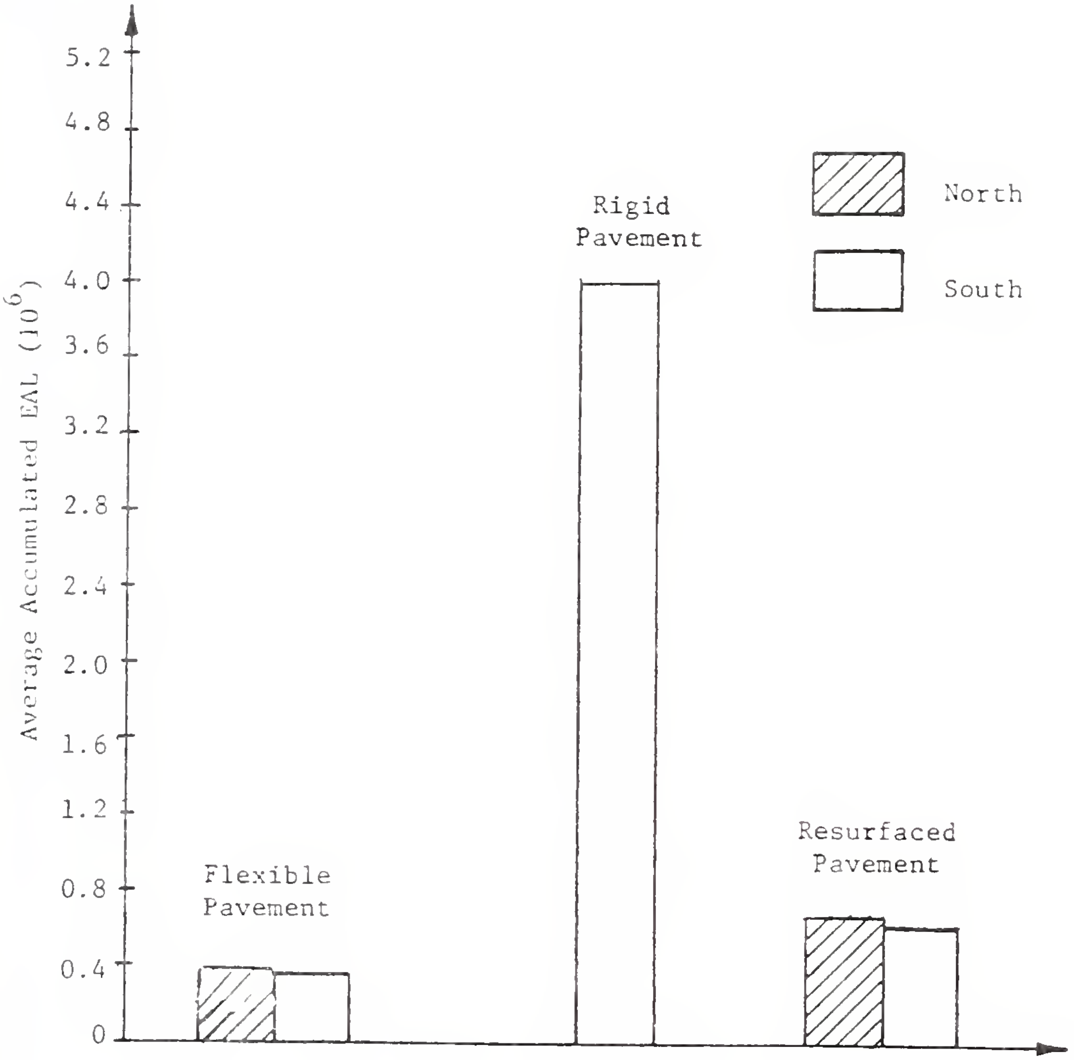

Figure 4.4 Average Accumulated EAL Values On the OSH System.

higher percent of trucks in the northern part where more truck traffic takes place along the industrial belt of Illinois, Indiana, Michigan and Ohio. This fact, coupled with harsher winters, may cause the maintenance costs to be higher in the northern part than in the southern part as indicated earlier.

Finally, the relative values of accumulated EAL were found to be consistent with the pavement type. For example, rigid pavements are usually constructed to carry higher traffic levels. This can be seen in Figures 4.3 and 4.4 where the accumulated EA values for rigid pavements are much higher than those for other pavement types. Although, the average age of the resurfaced pavement sections is less than that of flexible pavement sections, the accumulated EAL values on resurfaced pavement section are higher than flexible pavement sections. This is simply because the resurfaced pavements were rigid pavements before resurfacing took place, that is, they were planned to carry high traffic levels.

## 4.6 Chapter Summary

The data base described in Chapter 2 was used to perform tw basic types of analysis: total pavement maintenance expenditure and the distribution of total expenditure on different maintenance activities. In the first analysis, the average expenditur for each fiscal year (1980-83) was calculated for each highway category. This analysis showed a consistant trend of higher routine maintenance expenditure on OSH miles than on Interstate miles. Also, it was found that routine maintenance expenditure was higher in the northern zone than in the southern zone. This could be related to climatic effect. Finally, it was found that there was a noticeable difference in pavement maintenance expenditure on different pavement type-highway class combinations.

In the second analysis, the pavement routine maintenance activities were grouped into three groups: patching, sealing, and other. This analysis showed that most of the maintenance expenditure was related to patching and sealing activities. Also, the analysis showed that the portion of total expenditure allocated to patching activities in the north is higher than that in the south. On the other hand, this trend was reversed in the case of the portion of total expenditure in sealing activities. This may be related to the relatively milder winter in the southern zone which allows more time for sealing jobs to be undertaken in the fall season.

# CHAPTER 5

# CORRELATION ANALYSIS OF PAVEMENT MAINTENANCE EXPENDITURES

## 5.1 Introduction

In this Chapter, the results of a detailed statistical correlation analysis of pavement maintenance expenditures will be presented. The purpose of this analysis was to investigate the effect of pavement maintenance activities conducted in the past on current maintenance needs as well as the impact of performing different activities or groups of activities on each other. Four types of correlation analysis were included: (i) correlation between total maintenance costs of different years; (ii) correlation between individual activity costs of different years; (iii) correlation between fractions of total costs allocated to different activities or groups of activities in the same year; and (iv) correlation between fractions of total costs allocated to different activities or groups of activities in successive years.

## 5.2 Correlation Between Total Costs

The total costs are the summation of all individual activity costs in each of the fiscal years. All costs considered were in 1982-83 dollars. Statistical correlation was performed between the pavement maintenance expenditures of a given year against the maintenance expenditures of a past year or a number of years. As the available data concerned four years, 1980 through 1983, three cases of correlation were applied: case I, correlation between two successive years, that is 1980 with 1981, 1981 with 1982, and 1982 with 1983; case II, correlation between the average of two years´ expenditures against the third year, that is the average of 1980 and 1981 with 1982, and average of 1981 and 1982 with 1983; and case III, correlation between the average of three years´ expenditures against the fourth year, that is the average of 1980, 1981, and 1982 with 1983.

The results of the three cases are presented in Table 5.1. As may be seen from Table 5.1, there is a general trend for higher correlation values between total costs for the Interstate system than those for OSH system. For example, in case II analysis involving the average of two years with the third year, the average correlation coefficient is 0.77 for the Interstate system and 0.705 for OSH system, and in case III these values are .82 and 0.72, respectively. The results also showed that the correlation coefficient is improved with the increase in the number of past years considered. For instance, 0.65 was the correlation coefficient in case I for both Interstate and OSH systems, while the correlation coefficients in case II were 0.77 and 0.705 for the two systems, respectively, and in case III these values were 0.82 and 0.72, respectively.

Table 5.1 Correlation Analysis of Total Pavement Maintenance Expenditures.

| | Pearson Correlation Coefficient | | | | | |
|---|---|---|---|---|---|---|
| | Case I[1] | | Case II[2] | | Case III[3] | |
| | Interstate | Other State Highways | Interstate | Other State Highways | Interstate | Other State Highways |
| | 0.58 | 0.64 | 0.72 | 0.70 | 0.82 | 0.72 |
| | 0.65 | 0.67 | 0.81 | 0.71 | | |
| | 0.73 | 0.65 | | | | |
| Average | 0.65 | 0.65 | 0.77 | 0.705 | 0.82 | 0.72 |

[1] Each two successive years, 1980 with 1981, 1981 with 1982, and 1982 with 1983.

[2] Average of two years with the third year, 1980 and 1981 with 1982, and 1981 and 1982 with 1983.

[3] Average of three years with the fourth year, 1980, 1981, and 1982 with 1983.

## 5.3 Correlation Between Individual Activity Costs

The second set of analysis was carried out to investigate the correlation between individual activity costs to determine if a relationship exists between the past years′ or a number of years′ expenditures and a following years′ expenditures. As in the previous analysis, the three correlation cases (I, II, and III) were applied for each individual activity. The results of the three cases are shown in Table 5.2. The most important result is that patching and sealing activities (activities 201, 202, 206, and 207) showed the highest correlation values particularly when the past two or three years′ expenditures were considered (case II or III). As these activity costs represent more than 85% of total costs for the Interstate system and more than 65% for OSH system, a good estimation of these activity costs using previous expenditure records can lead to a good overall estimation of the total maintenance expenditures for a given year. Also, for these activities as well as for most of the other activities, the Interstate system correlation values were higher than those for the OSH system.

To summarize, the above two correlation studies showed that the past expenditures could be of significant importance when used in maintenance prediction models for both the total costs and individual activity costs. It should be noted here that the above results give a general indication

Table 5.2 Correlation Analysis of Individual Activity Costs

| Activity Number | Pearson Correlation Coefficient | | | | | |
|---|---|---|---|---|---|---|
| | Case I[1] | | Case II[2] | | Case III[3] | |
| | Interstate | Other State Highways | Interstate | Other State Highways | Interstate | Other State Highways |
| 201 | 0.73 | 0.69 | 0.82 | 0.71 | 0.82 | 0.72 |
| 202 | 0.63 | 0.24 | 0.76 | 0.27 | 0.76 | 0.33 |
| 203 | 0.16 | 0.06 | 0.21 | 0.04 | 0.23 | 0.02 |
| 205 | N.A. | 0.04 | N.A. | 0.06 | N.A. | 0.08 |
| 206 | 0.33 | 0.38 | 0.39 | 0.44 | 0.51 | 0.55 |
| 207 | 0.19 | 0.23 | 0.32 | 0.32 | 0.20 | 0.43 |
| 209 | 0.21 | 0.20 | 0.27 | 0.19 | 0.02 | 0.22 |
| 214 | 0.17 | 0.17 | 0.32 | 0.32 | 0.24 | 0.40 |
| 219 | 0.37 | 0.08 | 0.45 | 0.09 | 0.37 | 0.17 |

[1] Each two successive year, 1980 with 1981, 1981 with 1982, and 1982 with 1983.

[2] Average of two years with the third year, 1980 and 1981 with 1982, and 1981 and 1982 with 1983.

[3] Average of three years with the fourth year, 1980, 1981, and 1982 with 1983.

of the possible use of past records to predict future maintenance needs; however, no specific relationships could be derived from this analysis.

### 5.4 Correlation Between Fractions of Total Cost Allocated To Activities in Same Fiscal Year

While the previous correlation analysis was restricted to the use of the dollar amount (expenditure) of different activities, the present analysis considered the relative contribution of different activities to the total expenditure. This was done through the use of the fraction or percent of an activity cost of the total expenditure in each section. The previous correlation analysis, where dollar amount of expenditures was used, indicated that a high level of expenditures in previous years meant a high level of expenditures also in subsequent years, unless a major maintenance took place in the mean time. On the other hand, the correlation analysis involving the fraction or percent of total cost in various activities can indicate the relative effect of expenditure levels of these activities on each other.

The first part of this analysis considered the individual activities. Correlation coefficient for each pair of nine activities was calculated for each of the four fiscal years. To account for geographical location effect, four correlation matrices were developed: Interstate north, Interstate south, OSH north, and OSH south. Out of the nine activities, a consistent negative correlation was found between shallow patching (activity 201) and crack sealing (activity 207). The rest of the individual activity intercorrelations were found to be insignificant in most cases. Figure 5.1 presents a summary of the correlation values between percent of total cost allocated to shallow patching and that allocated to crack sealing. For example, considering the case of Interstate north, in fiscal year 1981 the correlation between shallow patching and crack sealing fractions of total cost is -.56. This means that the more crack sealing performed on a highway section, the less shallow patching is required in the same fiscal year. It can be noted in Figure 5.1 that the correlation value varies from year to year, from highway system to highway system, and from location to location; however, the variation is not significant and an overall average correlation of -0.40 could be assumed to exist between the shallow patching and crack sealing activities. It should be noted also that all correlation values in Figure 5.1 are significant at 90% or 95% levels of confidence. The principal implication of these results is that the portion of total cost allocated to shallow patching is significantly affected by the amount of crack sealing performed in the same fiscal year. That is, prewinter preventive maintenance in terms of crack sealing could effectively reduce the amount of post winter repair needed in terms of shallow patching. The other implication

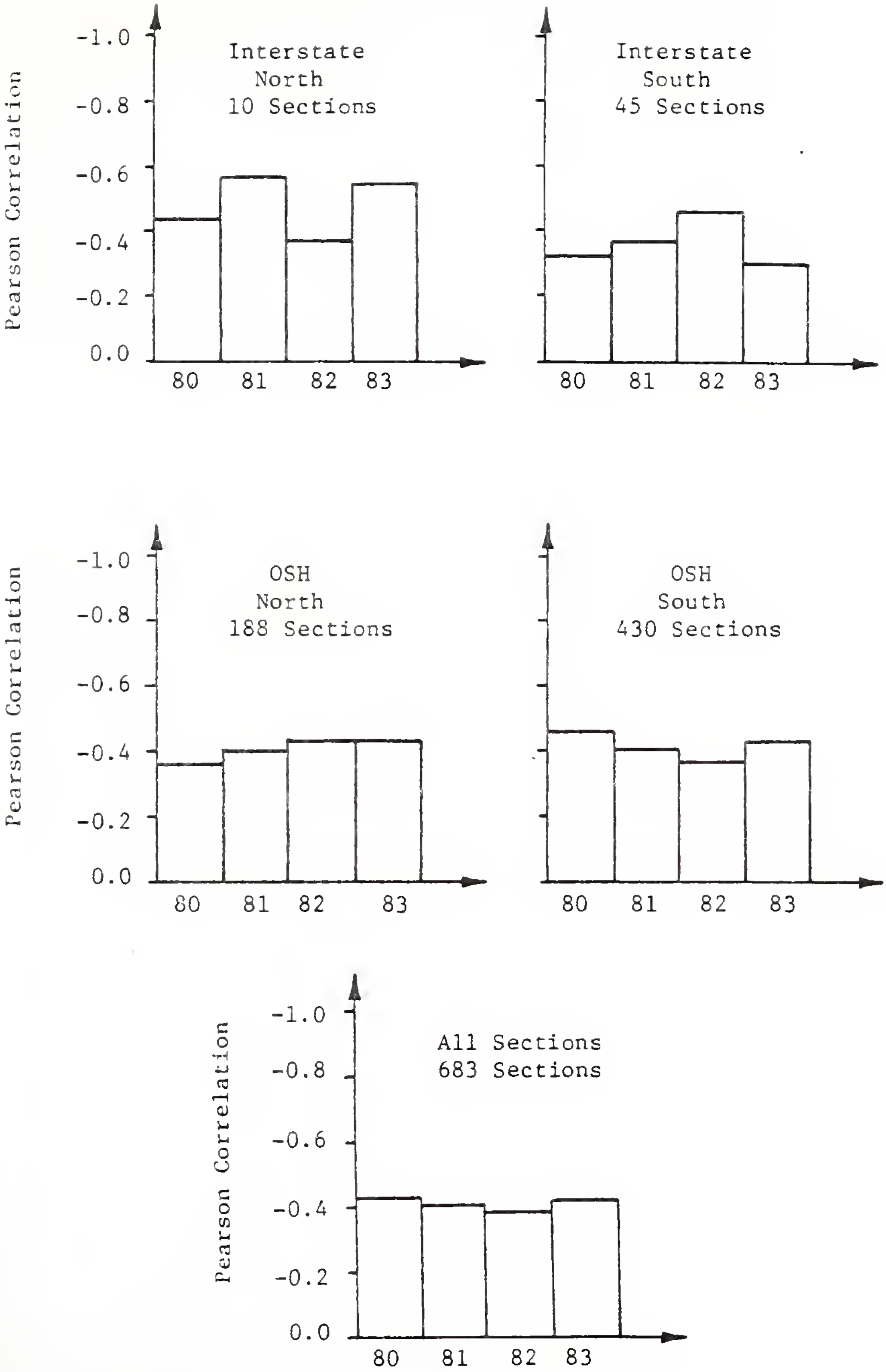

Figure 5.1 Correlation Between Fractions of Total Cost Allocated to Patching and Sealing Activities.

of these results is that in order to predict shallow patching expenditures one should consider the amount of crack sealing performed in the same fiscal year.

The second part of this analysis considered groups of pavement maintenance activities. Three basic groups were considered: patching (activities 201, 202 and 203); sealing (activities 205, 206, and 207); and others (activities 209, 214 and 219) To avoid the effect of the relatively high costs in terms of $/lane-mile of activities 203 and 205, it was decided to exclude these two activities from the analysis performed in this section. Thus, the patching group in this analysis was simply the sum of shallow and deep patching activities and sealing group was the sum of longitudinal and other crack sealing activities. Fractions of total expenditure in each highway section allocated to each of these groups were then introduced as variables to the correlation analysis. Table 5.3 is a summary of the results of this analysis. The results showed a strong negative correlation between patching and sealing groups, similar to the results of the previous correlation analysis. The only difference is that the magnitude of the correlation coefficient associated with the four activities considered in this analysis are higher than those of previous analysis, that is the effect of the results of this analysis is more critical to the overall expenditure prediction process. It may also be noted that the correlation values related to the

Table 5.3 Correlation Analysis of Maintenance Activity Groups

| | Pearson Correlation For | | |
|---|---|---|---|
| | Patching vs. Sealing | Patching vs. Others | Sealing vs. Others |
| Interstate North | (10 Sections) | | |
| F.Y.[1] 1980 | -0.55 | 0.22 | -0.24 |
| 1981 | -0.46 | 0.29 | -0.48 |
| 1982 | -0.31 | -0.59 | -0.07 |
| 1983 | -0.64 | 0.24 | -0.45 |
| Interstate South | (45 Sections) | | |
| F.Y. 1980 | -0.57 | -0.19 | -0.34 |
| 1981 | -0.65 | -0.27 | -0.35 |
| 1982 | -0.57 | -0.22 | -0.18 |
| 1983 | -0.43 | -0.18 | -0.18 |
| OSH North | (188 Sections) | | |
| F.Y. 1980 | -0.44 | -0.13 | -0.11 |
| 1981 | -0.48 | -0.14 | -0.12 |
| 1982 | -0.49 | -0.28 | -0.15 |
| 1983 | -0.45 | -0.11 | -0.11 |
| OSH South | (430 Sections) | | |
| F.Y. 1980 | -0.49 | -0.04 | - .09 |
| 1981 | -0.45 | -0.16 | - .07 |
| 1982 | -0.43 | -0.11 | -0.14 |
| 1983 | -0.49 | -0.07 | -0.17 |
| All Sections | (683 Sections) | | |
| F.Y. 1980 | -0.49 | - .08 | -0.12 |
| 1981 | -0.48 | -0.16 | -0.09 |
| 1982 | -0.45 | -0.18 | -0.15 |
| 1983 | -0.49 | -0.08 | -0.16 |

[1] Fiscal Year

Interstate system tend to be higher than those related to the OSH. This may be explained by the fact that jobs performed on the Interstate system require more elaborate safety preparation and other controls than on OSH.

The final conclusion of this analysis is that prediction models for individual pavement maintenance groups cannot be developed accurately without considering the intercorrelation between individual maintenance activities or groups.

## 5.5 Correlation Between Fractions of Total Cost Allocated to Activities in Successive Years

The analysis discussed so far showed that an increased level of preventive measure taken for the pavement in terms of increased sealing jobs tends to reduce the amount of patching repairs required later during the same fiscal year. The analysis considered in this section examined the possible correlation between the level of activity performed in one year and that performed in the proceeding year or years For example, does higher portion of total expenditure allocated to patching group in fiscal year 1980 reduce the amount of sealing required in fiscal year 1981? A complete correlation analysis, as that described in the previous section, was conducted. The results showed very low correlation between individual activities as well as between group of activities. Thus, it can be concluded that the fraction of total cost allocated to a particular activity or a group of activities in a year is not related to the fraction or fractions of the previous year or years.

## 5.6 Chapter Summary

A detailed statistical correlation analysis of pavement maintenance expenditure was performed to investigate the effect of pavement maintenance activities conducted in the past on current maintenance needs. Four sets of correlation analysis were included: (i) correlation between total maintenance expenditure of different years; (ii) correlation between individual activity expenditure of different years; (iii) correlation between fractions of total expenditure allocated to different activities or groups of activities in the same year; and (iv) correlation between fractions of total expenditure allocated to different activities or groups of activities in successive years.

In the first correlation analysis, it was found that the average expenditure of the past two or three years was highly correlated with the next year′s expenditure. Also, the correlation coefficients were found to be higher for the Interstate system then for the OSH system.

In the analysis involving individual activities expenditure, results similar to those of the first analysis were obtained for patching (activities 201 and 202) as well as for sealing activities (activities 206 and 207). Other activities did not show high correlation.

The third analysis showed high negative correlation between sealing expenditure in fall season (before winter) and patching expenditure after winter. This indicated the importance of sealing as preventive maintenance activities which may result in a reduction in the amount of repair or emergency activities in terms of patching.

In the fourth analysis very low correlation coefficients were observed.

# CHAPTER 6

# DEVELOPMENT OF PREDICTION MODELS

## 6.1 Introduction

One of the objectives of this study was to demonstrate how the already available data from the IDOH can be used to develop prediction models to serve the general purpose of network level planning for both pavement routine maintenance yearly program and for decisions concerning major maintenance activities such as resurfacing, rehabilitation and reconstruction.

In this Chapter, the information included in the data base as described in Chapter 2 was utilized to develop statistical models that express the expected pavement maintenance costs as function of highway system, pavement type, traffic level, and climatic zone.

## 6.2 The Study Unit

In developing the statistical models it was necessary to identify the study unit to obtain the necessary information. A pavement contract would have been the ideal unit in this study. However, as indicated earlier, the maintenance expenditure data are recorded by highway section rather than by contract. This situation dictated the use of a highway section as the study unit in developing the statistical models. Moreover, not all highway section data could be used in the analysis. The reason is that some of the highway sections include more than one pavement type (more than one contract). It was decided to consider only those highway sections that were homogeneous, sections having same pavement type and characteristics along their entire length. The data base was carefully investigated to specify these sections along with the corresponding information, such as highway system, pavement type, age, traffic (both ADT and EAL), climatic zone and different routine maintenance activity costs during the last four fiscal years.

## 6.3 Multiple Regression Models For Total Pavement Maintenance Cost Prediction

Multiple regression analysis was performed to develop pavement maintenance prediction models. Six categories were identified: Interstate flexible pavement; Interstate rigid pavement; Interstate resurfaced pavement; OSH flexible pavement; OSH rigid pavement and OSH resurfaced pavement. Each of these categories was considered separately and ten different regression models were tested to fit the data. Five criteria were considered in selecting the best regression model: (i) the general goodness-of-fit represented by the coefficient of multiple determination ($R^2$); (ii) the general linearity test for the model through the application of the general `F´ test; (iii) the significance of individual coefficients of the model through the `t´ or `F´ tests; (iv) testing for the presence of auto correlation problems through the Durbin-Watson test and (v) the percent of outliers. For each model within each of the six categories mentioned above, the five criteria were applied and the best model was specified. An attempt was made during the analysis to have the same model type for the six categories so that comparison of the effects of different factors could be facilitated.

After an intensive search, one model appeared to satisfy all required conditions for the six categories. This model is given in Equation 6.1.

$$\mathrm{Log}_{10}\,(TC) = a\,\mathrm{Log}_{10}\,(\Sigma EAL) + b\,\mathrm{Log}_{10}\,(\Sigma EAL) * (Z) + c\,(Z) \qquad (6.1)$$

where,

TC = total pavement maintenance cost in $/lane-mile/year;

ΣEAL = accumulated equivalent axle load applications during the entire age of the pavement section (in thousands).

Z = dummy variable to represent the zone in which the section is located. This variable takes the value 1 when the pavement section is located in the northern zone of Indiana (refer to Figure 2.5) and the value of 0 if located in the southern zone.

The purpose of including the variable `ΣEAL´ in the model was to measure the effect of traffic level on pavement maintenance costs. The variable `Z´ was included to measure the effect of climatic zone (north or south) of a section on its pavement maintenance costs. Finally, the third term `ΣEAL * Z´ was introduced to measure the effect of the interaction between traffic level and climatic zone.

In almost all cases, and particularly in the type of models presented in equation 6.1, the main effect of the variable `Z´; was found to be insignificant. This can be explained by the fact that the dummy variable `Z´ in reality measures the effect of the `difference´ between the two zones and not the direct effect of the variable climatic zone itself. However, it was found in all cases that the interaction between traffic level and climatic zone was significant. Consequently, the model in equation 6.1 was reduced to the form shown in equation 6.2.

$$\mathrm{Log}_{10}\,(\mathrm{TC}) = a\,\log_{10}\,(\Sigma \mathrm{EAL}) + b\,\log_{10}\,(\Sigma \mathrm{EAL}) * Z \tag{6.2}$$

The models for the six categories are given in Equations 6.3 to 6.8 below.

For Interstate flexible pavement:

$$\log_{10}(TC) = 0.61 \log_{10}(\Sigma EAL) \qquad (6.3)$$

For Interstate rigid pavement:

$$\log_{10}(TC) = 0.530 \log_{10}(\Sigma EAL) + 0.032 \log_{10}(\Sigma EAL) * (Z) \qquad (6.4)$$

For Interstate resurfaced pavement:

$$\log_{10}(TC) = 0.590 \log_{10}(\Sigma EAL) \qquad (6.5)$$

For OSH flexible pavement:

$$\log_{10}(TC) = 0.974 \log_{10}(\Sigma EAL) + 0.24 \log_{10}(\Sigma EAL) * (Z) \qquad (6.6)$$

For OSH rigid pavement:

$$\log_{10}(TC) = 0.681 \log_{10}(\Sigma EAL) \qquad (6.7)$$

For OSH resurfaced pavement:

$$\log_{10}(TC) = 0.850 \log_{10}(\Sigma EAL) + 0.040 \log_{10}(\Sigma EAL) * (Z) \qquad (6.8)$$

As may be noticed, Equations 6.3, 6.5, and 6.7 do not include the second term (interaction between traffic level and zone). This is because the number of available sections in the northern zone for the corresponding categories was either very small or nonexistent. For example, as indicated in Table 4.2, no section was found in the northern zone for the Interstate flexible pavement category. Similarly, not enough sections were found in the northern zone for Interstate resurfaced pavement (Equation 6.5), and for OSH rigid pavement (Equation 6.7). It should be mentioned, however, that these three pavement categories comprised only 15% of the total mileage of the state highway system and the other three categories represent the remaining 85%. It should also be noted that the model presented in Equation 9.4 for the Interstate rigid pavement includes both jointed reinforced concrete and continuous reinforced concrete pavements. However, the preliminary work on this study reported in Reference (73) indicated a higher cost for continuous reinforced concrete sections than for jointed reinforced concrete sections. It was observed that the maintenance cost of continuous reinforced sections was about 15% to 35% higher than that of jointed reinforced sections subject to the same traffic level.

A summary of the characteristics of the models presented in Equations 6.3 to 6.8 is given in Table 6.1. As shown in Table 6.1, a relatively high $R^2$ was obtained for all category models. Also, the general linearity test indicated a very good linear fit for all models. Furthermore, the significance test for the coefficient `a´ for the variable `ΣEAL´; (accumulated traffic level) showed a high level

Table 6.1 Statistical Characteristics of Total Pavement Maintenance Cost Prediction Models

| Criterion | Interstate Flexible | Interstate Rigid | Interstate Resurfaced | OSH Flexible | OSH Rigid | OSH Resurfaced |
|---|---|---|---|---|---|---|
| Coefficient of Determination ($R^2$) | 0.87 | 0.87 | 0.81 | 0.85 | 0.87 | 0.80 |
| Linearity Test | | | | | | |
| F value | 190 | 1750 | 52 | 1199 | 100 | 218 |
| α level | 0 | 0 | 0.001 | 0 | 0.002 | 0 |
| Significance Test for Coefficients | | | | | | |
| $Log_{10}$ (ΣEAL) F value | 190 | 1918 | 52 | 1738 | 100 | 243 |
| α level | 0 | 0 | .001 | 0 | 0.002 | 0 |
| $Log_{10}$ (ΣEAL) * Location F value | --- | 3.01 | --- | 2.70 | --- | 2.87 |
| α level | --- | 0.09 | --- | 0.10 | --- | 0.09 |
| Durbin-Watson Test | | | | | | |
| D value | 0.91 | 1.30 | 0.85 | 1.97 | 3.04 | 1.43 |
| Test Result[1] | Not Valid | No | Not Valid | No | No | No |
| Percent Outliers | 0 | 4.55 | 0 | 4.27 | 0 | 2.00 |

[1] No = no auto correlation

Yes = auto correlation exists

Not Valid = no conclusion can be made

of confidence (low $\alpha$ value). The level of significance of the interaction term (between traffic and location) is lower than that of the traffic level, however, it could be considered significant at 90% level of confidence in all cases considered, as shown in Table 6.1. The Durbin-Watson test showed that no auto correlation existed in the four models (all OSH models and Interstate rigid pavement). Finally, the number of outliers (observations outside the range of ± two standard deviations) was specified and presented in terms of the percent of the total number of observations as shown in Table 6.1. A maximum of about 4.5% of total observations was found to be outside of the range in case of the Interstate rigid pavement.

Generally, it is believed that the choice of the model presented in Equation 6.2 was appropriate for all categories based on the results summarized in Table 6.1. One particular note that should be mentioned here is that during the analysis, different models were tested for those categories that had enough data (OSH flexible pavement, OSH resurfaced pavement, and Interstate rigid pavement). Once an acceptable model was obtained for these categories, as shown in Equation 6.2, the general form was simply applied to the other categories where the available data were not sufficient.

### 6.3.1 Implications of Total Maintenance Cost Prediction Models

While the maintenance rates developed and summarized in Chapter 7 provide an overall average of unit maintenance costs for different highway system, pavement type and location combinations, the models presented in Equations 6.3 to 6.8 add a new dimension; the effect of traffic level and its interaction with climatic zone on the unit cost values.

The effect of traffic and its interaction with geographic location can be best demonstrated through the examination of Tables 6.2 to 6.7 and the graphical presentations in Figures 6.1 to 6.3. In these Tables, the average pavement maintenance costs at typical traffic levels ($\Sigma$EAL) for each highway system, pavement type and climatic zone (north and south) combinations are presented. It is clear that for the same pavement type and traffic level, the average maintenance cost of the Interstate sections is less than that of the OSH. This could be traced to the fact that the Interstate system received a higher rate of major maintenance activities, particularly in the last few years, and this in turn might have reduced the need for higher levels of routine maintenance. In general, it can also be expected that maintenance levels differ significantly by pavement type within a particular highway system. For example, in both the Interstate and OSH systems, at the same traffic levels, the highest unit pavement maintenance cost was observed in flexible pavement followed by resurfaced pavements and then rigid pavement. However, an important find-

Table 6.2 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on Interstate Flexible Pavement.

| Accumulated EAL $(10^3)$ | Estimated Maintenance Cost ($/LM/Year)[1] | | |
|---|---|---|---|
| | South | North | Ratio $(\frac{North}{South})$ |
| 1,000 | 68 | N.A. | N.A. |
| 2,000 | 103 | N.A. | N.A. |
| 3,000 | 132 | N.A. | N.A. |
| 4,000 | 157 | N.A. | N.A. |
| 5,000 | 180 | N.A. | N.A. |
| 6,000 | 202 | N.A. | N.A. |
| 7,000 | 222 | N.A. | N.A. |
| 8,000 | 240 | N.A. | N.A. |
| 9,000 | 258 | N.A. | N.A. |
| 10,000 | 275 | N.A. | N.A. |

[1] From Equation 6.3

Table 6.3 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on Interstate Rigid Pavement.

| Accumulated EAL $(10^3)$ | Estimated Maintenance Cost ($/LM/Year)[1] | | |
|---|---|---|---|
| | South | North | Ratio $(\frac{North}{South})$ |
| 5,000 | 91 | 120 | 1.31 |
| 10,000 | 132 | 177 | 1.34 |
| 15,000 | 163 | 222 | 1.36 |
| 20,000 | 190 | 261 | 1.37 |
| 25,000 | 214 | 296 | 1.38 |
| 30,000 | 236 | 328 | 1.39 |
| 35,000 | 256 | 358 | 1.40 |
| 40,000 | 275 | 386 | 1.40 |
| 45,000 | 293 | 412 | 1.41 |
| 50,000 | 309 | 437 | 1.41 |

[1] From Equation 6.4

Table 6.4 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on Interstate Resurfaced Pavement.

| Accumulated EAL $(10^3)$ | Estimated Maintenance Cost (\$/LM/Year)[1] | | |
|---|---|---|---|
| | South | North | Ratio $(\frac{North}{South})$ |
| 1,000 | 59 | N.A. | N.A. |
| 2,000 | 88 | N.A. | N.A. |
| 3,000 | 113 | N.A. | N.A. |
| 4,000 | 133 | N.A. | N.A. |
| 5,000 | 152 | N.A. | N.A. |
| 6,000 | 169 | N.A. | N.A. |
| 7,000 | 186 | N.A. | N.A. |
| 8,000 | 201 | N.A. | N.A. |
| 9,000 | 215 | N.A. | N.A. |
| 10,000 | 229 | N.A. | N.A. |

[1] From Equation 6.5

Table 6.5 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on OSH Flexible Pavement.

| Accumulated EAL $(10^3)$ | Estimated Maintenance Cost (\$/LM/Year)[1] | | |
|---|---|---|---|
| | South | North | Ratio $(\frac{North}{South})$ |
| 50 | 45 | 50 | 1.10 |
| 100 | 88 | 99 | 1.10 |
| 150 | 131 | 149 | 1.14 |
| 200 | 174 | 198 | 1.14 |
| 250 | 216 | 247 | 1.15 |
| 300 | 258 | 297 | 1.15 |
| 350 | 300 | 346 | 1.15 |
| 400 | 342 | 395 | 1.16 |
| 450 | 383 | 445 | 1.16 |
| 500 | 425 | 494 | 1.16 |

[1] From Equation 6.6

Table 6.6 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on OSH Rigid Pavement.

| Accumulated EAL ($10^3$) | Estimated Maintenance Cost ($/LM/Year)[1] | | |
|---|---|---|---|
| | South | North | Ratio $(\frac{\text{North}}{\text{South}})$ |
| 1,000 | 110 | N.A. | N.A. |
| 2,000 | 177 | N.A. | N.A. |
| 3,000 | 233 | N.A. | N.A. |
| 4,000 | 284 | N.A. | N.A. |
| 5,000 | 330 | N.A. | N.A. |
| 6,000 | 374 | N.A. | N.A. |
| 7,000 | 415 | N.A. | N.A. |
| 8,000 | 456 | N.A. | N.A. |
| 9,000 | 492 | N.A. | N.A. |
| 10,000 | 530 | N.A. | N.A. |

[1] From Equation 6.7

Table 6.7 Estimated Pavement Routine Maintenance Cost for Typical Traffic Levels on OSH Resurfaced Pavement.

| Accumulated EAL ($10^3$) | Estimated Maintenance Cost ($/LM/Year)[1] | | |
|---|---|---|---|
| | South | North | Ratio $(\frac{\text{North}}{\text{South}})$ |
| 100 | 50 | 60 | 1.20 |
| 200 | 90 | 112 | 1.24 |
| 300 | 127 | 160 | 1.26 |
| 400 | 163 | 207 | 1.28 |
| 500 | 196 | 252 | 1.29 |
| 600 | 230 | 297 | 1.29 |
| 700 | 262 | 341 | 1.30 |
| 800 | 293 | 383 | 1.31 |
| 900 | 324 | 426 | 1.31 |
| 1,000 | 354 | 468 | 1.32 |

[1] From Equation 6.8

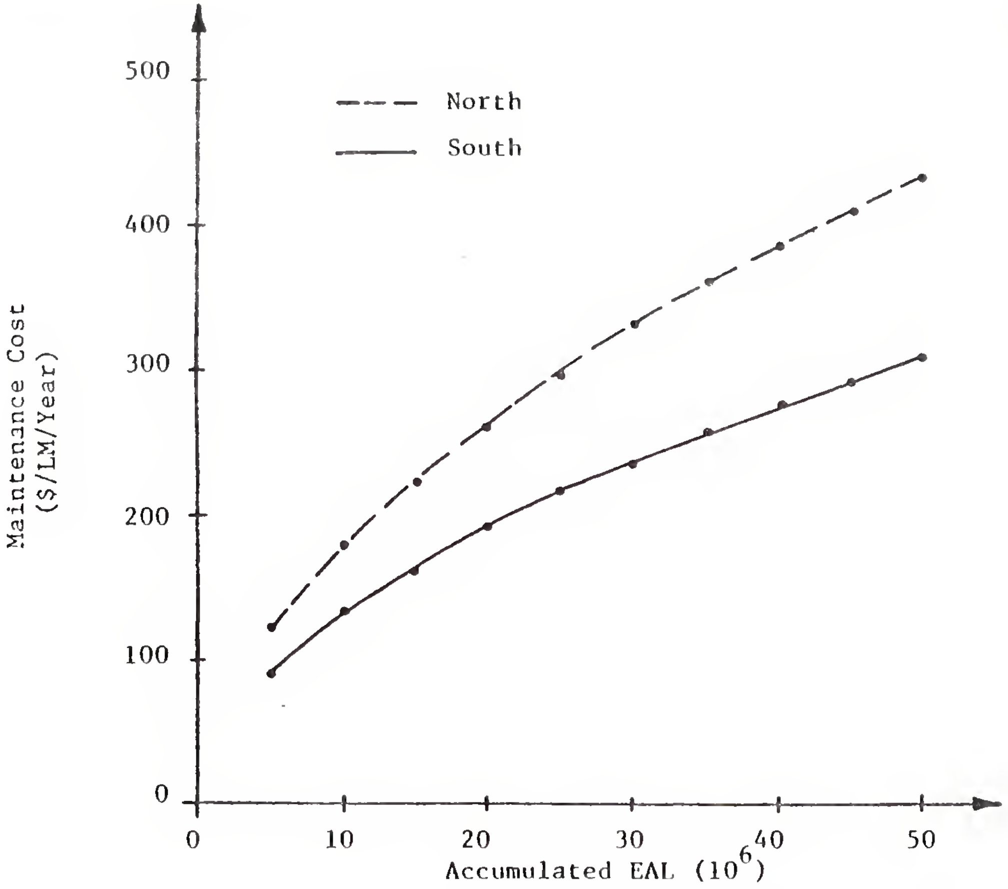

Figure 6.1 Estimated Pavement Maintenance Costs for Interstate Rigid Pavement

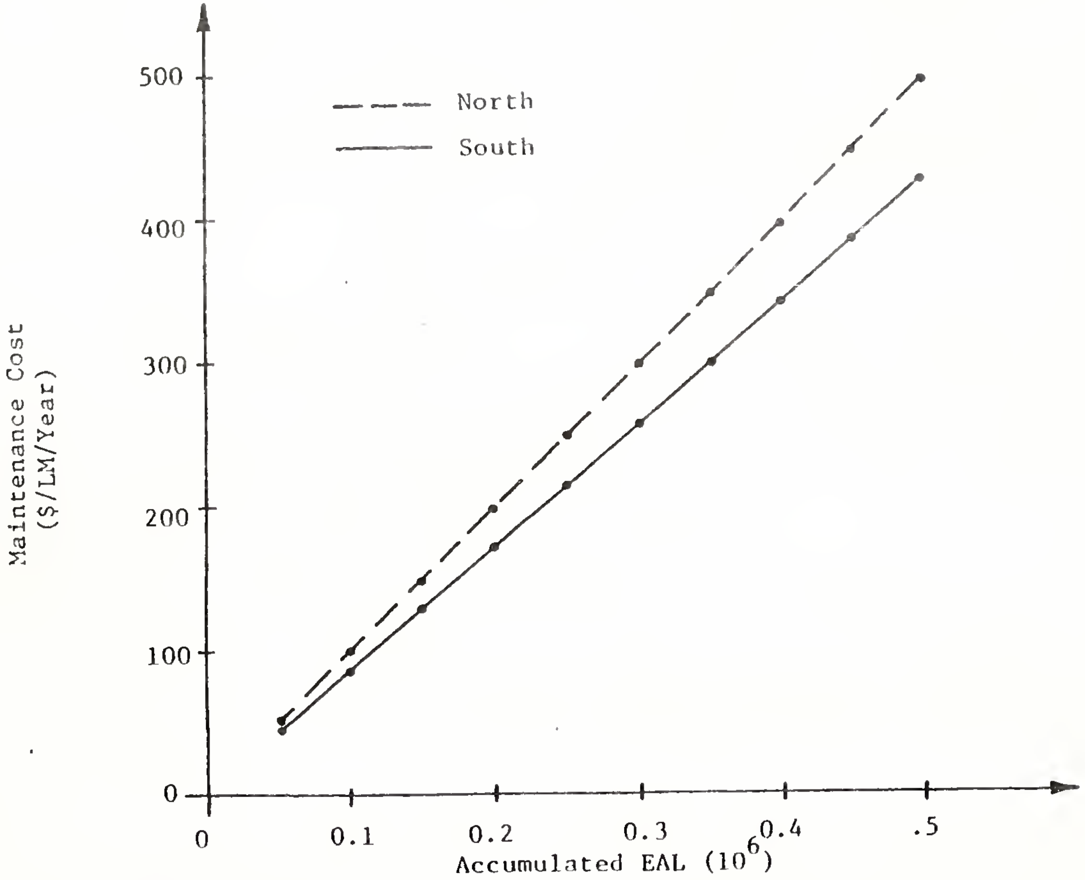

Figure 6.2 Estimated Pavement Maintenance Costs for OSH Flexible Pavement

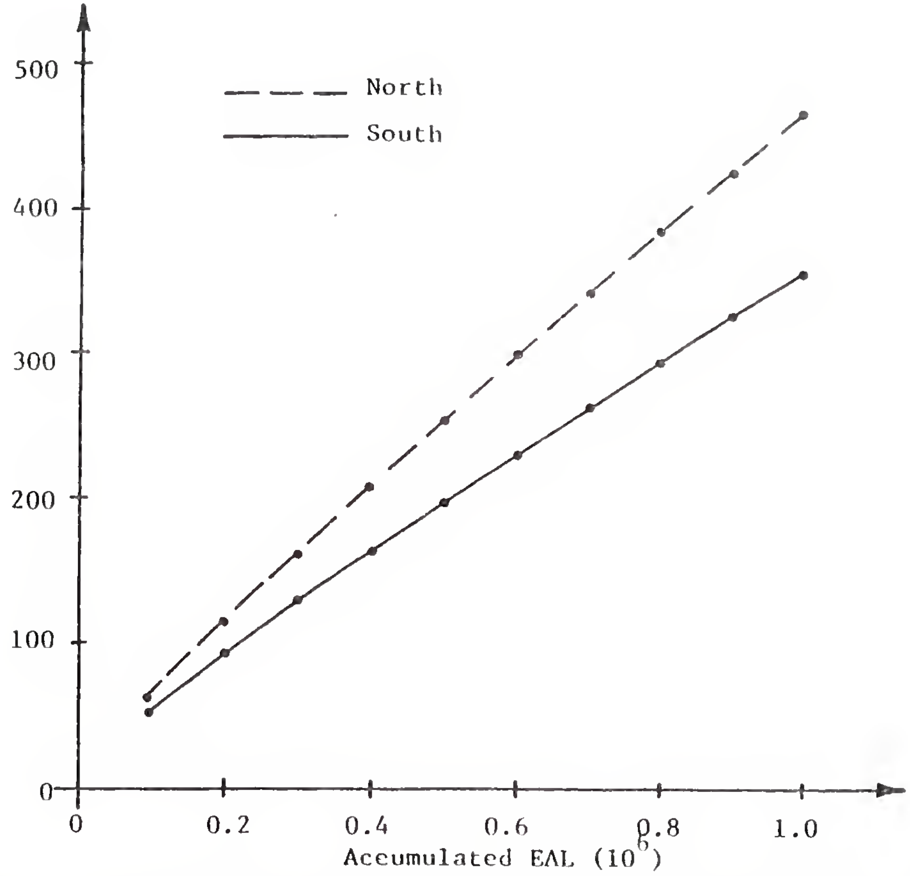

Figure 6.3 Estimated Pavement Maintenance Costs for OSH Resurfaced Pavement

ing of this analysis was that the effect of traffic level on such difference in maintenance costs is not constant. To illustrate, the Interstate rigid and resurfaced pavements can be considered. At a traffic level of 5,000,000 accumulated EAL, the ratio between maintenance cost of resurfaced pavement and rigid pavement is 1.67, while this ratio becomes 1.75 at traffic level of 10,000,000 accumulated EAL. Similarly, for the OSH system, at traffic levels of 500,000 and 1,000,000 accumulated EAL, the corresponding cost ratios are 2.8 and 3.2, respectively. Such information can be extreme importance in making decisions concerning the timing of resurfacing projects.

An important application of these models is in assessment of the effect of climatic zone and of the interactive effect of traffic level and climatic zone on pavement maintenance cost. The effect of climatic zone on maintenance costs could be easily seen from Equations 6.4, 6.6 and 6.8 for the Interstate rigid pavement, OSH flexible pavement, and OSH resurfaced pavement, respectively. It is clear that, in general, pavement maintenance costs in the northern part are higher than in the southern part. The models, however, not only confirm the geographic difference in maintenance costs, but they also point out that this difference increases as the traffic level increases due to interaction effect. For example, for the Interstate rigid pavement, at relatively low traffic level of 1,000,000 accumulated EAL, the pavement maintenance cost in the northern zone is about 24% higher than that in the southern zone; while at higher level of traffic of 45,000,000 accumulated EAL, the northern zone average cost is 40% higher than that of the southern zone. The difference between 40% and 24% at traffic levels of 5,000,000 and 45,000,000 could be attributed to the interaction effect between traffic level and climatic zone. For the OSH flexible pavement, the ratio between average cost in the northern zone and that in the southern zone ranges from 1.10 at relatively low traffic level to 1.16 at higher traffic level. Similarly, for the OSH resurfaced pavement, the corresponding ratios are 1.20 and 1.32, respectively. The main conclusion that can be made from these results is that at higher traffic level, the effect of climatic zone (weather effects) tend to be more severe. However, the degree of interaction is significantly dependent on the pavement type. For example, the unit maintenance cost for OSH flexible pavement in the northern zone is about 16% higher than that in the southern zone at a traffic level of 400,000 EAL (Table 6.5), while this percentage is about 31% for OSH resurfaced pavement at the same traffic level (Table 6.7). This trend is consistent at all levels of traffic and it can be concluded that the effect of climatic zone (weather factor) on maintenance cost is more pronounced in resurfaced pavement.

## 6.4 Multiple Regression Models For Maintenance Group Cost Prediction Models

As indicated in Chapter 5, pavement maintenance activities can be grouped into three major categories: patching, sealing and others. Prediction of the level of a particular activity or a group of activities is rather a complex task and often it is done through a condition survey of the existing pavements. However, for the relatively aggregate level of this study, an overall indication of the distribution of total maintenance cost in different activity groups is sufficient.

These models provide a powerful tool to estimate the portions of total maintenance cost that can be attributed to different activity groups such as patching and sealing. In addition, these models can be used to gain insight into the interaction of various maintenance activities under different levels of traffic.

To develop such models, the information presented in Chapters 4 and 5 was utilized. In this section models developed for patching and sealing are discussed. Patching and sealing activities comprise about 85% of the total pavement maintenance cost and there is a high correlation between patching and sealing performed in the same fiscal year. The analysis of Chapter 5 indicated that this correlation could be as high as 0.6 (between patching and sealing). The scheduling of different maintenance activities in a fiscal year adds a particular characteristic to the correlation between patching and sealing. This is because sealing activities usually proceed patching activities within a fiscal year. Sealing activities take place in the late summer through fall, while patching usually takes place during the spring season after the winter. It should be mentioned here that there might be some variation in scheduling of these activities, however, the majority of sealing and patching jobs occurs during the periods mentioned.

A high correlation between patching and sealing in a fiscal year is in fact a one-way correlation that indicates that the amount of patching done in a year is generally dependent upon the extent of sealing performed before the winter. However, the sealing activity does not depend on patching activity.

The general type of regression models for patching and sealing follows the form presented in Equation 6.2. Equations 6.9 to 6.20 are the models developed for sealing and patching for each highway category.

For Interstate flexible pavement:

$$PS = 0.185 * \text{Log}_{10} (\Sigma EAL) \qquad (6.9)$$

$$PP = 0.182 * \log_{10} (\Sigma EAL) - 0.670 * PS \qquad (6.10)$$

where,

PS = percent of total pavement maintenance cost allocated to sealing group;

PP = percent of total pavement maintenance cost allocated to patching group.

For Interstate rigid pavement:

$$PS = 0.098 * \text{Log}_{10} (\Sigma EAL) - .015 * \text{Log}_{10} (\Sigma EAL) * Z \quad (6.11)$$

$$PP = 0.206 * \text{Log}_{10} (\Sigma EAL) - 0.023 * \text{Log}_{10} (\Sigma EAL) * Z - .998\ PS \quad (6.12)$$

For Interstate resurfaced pavement:

$$PS = 0.115 * \log_{10} (\Sigma EAL) \quad (6.13)$$

$$PP = 0.186 * \log_{10} (\Sigma EAL) - 0.621 * PS \quad (6.14)$$

For OSH flexible pavement:

$$PS = 0.22 * \text{Log}_{10} (\Sigma EAL) - 0.074 * \log_{10} (\Sigma EAL) * Z \quad (6.15)$$

$$PP = 0.346 * \log_{10} (\Sigma EAL) + 0.025 \log_{10} (\Sigma EAL) * Z - .786\ PS \quad (6.16)$$

For OSH rigid pavement:

$$PS = 0.1075 * \log_{10} (\Sigma EAL) \qquad (6.17)$$

$$PP = 0.150 * \log_{10} (\Sigma EAL) - 0.135\ PS \qquad (6.18)$$

For OSH resurfaced pavement:

$$PS = 0.196 * \text{Log}_{10} (\Sigma EAL) - 0.0617 * \text{Log}_{10} (\Sigma EAL) * Z \qquad (6.19)$$

$$PP = 0.228 * \text{Log}_{10} (\Sigma EAL) + 0.011 * \text{Log}_{10} (\Sigma EAL) * Z - 0.55 * PS \qquad (6.20)$$

### 6.4.1 Implications of Maintenance Group Cost Prediction Models

The models presented in Equations 6.9 to 6.20 are for sealing and patching costs in terms of the percent of total pavement maintenance cost required at different traffic levels and zones (north and south). As may be seen, sealing prediction models are functions of traffic level (accumulated EAL) and zone (north and south), while patching prediction models are functions of traffic level, zone and also the level of sealing performed in the same fiscal year. The reason for this form is that while patching level is highly correlated with the sealing level, sealing activity does not show significant dependence on the patching level. This is mainly because of the order of scheduling of most sealing jobs before patching job within the same fiscal year. The models showed a good fit to the available data. Coefficient of determination ($R^2$) values along with other statistical characteristics of sealing and patching prediction models are summarized in Tables 6.8 and 6.9. Also, in Figures 6.4 to 6.6, graphical presentations of sealing and patching percentages of the total cost at typical traffic levels are presented.

The first implication of Figures 6.4 through 6.6 is that both sealing and patching shares of the total pavement maintenance cost increase as the traffic level increases. This is expected because an increasing traffic level accelerates the pavement distress process requiring an increased level of pavement maintenance, primarily sealing and patching. However, the rate of increase in patching share as traffic level increases is higher than that in sealing.

Secondly, both rigid and resurfaced pavements show similar trend in terms of higher patching and sealing shares in the south. This trend, however, was found to be different in the case of flexible pavement (Figure 6.5) where patching shares are higher in the north than in the south. This could be due to the relatively low level of sealing in the northern part because of the short period available in

Table 6.8 Statistical Characteristics of Sealing Prediction Models

| Criterion | Interstate Flexible | Interstate Rigid | Interstate Resurfaced | OSH Flexible | OSH Rigid | OSH Resurfaced |
|---|---|---|---|---|---|---|
| Coefficient of Determination ($R^2$) | 0.87 | 0.81 | 0.91 | 0.78 | 0.82 | 0.81 |
| Linearity Test | | | | | | |
| F value | 27.96 | 40.71 | 45.53 | 131.94 | 13.89 | 59.48 |
| α level | 0.006 | 0 | 0.003 | 0 | 0.034 | 0 |
| Significance Tests for Coefficients | | | | | | |
| $\mathrm{Log}_{10}$ (ΣEAL) | | | | | | |
| F value | 27.96 | 66.31 | 45.53 | 226.93 | 13.89 | 91.82 |
| α level | 0.006 | 0 | 0.003 | 0 | 0.034 | 0 |
| $\mathrm{Log}_{10}$ (ΣEAL) * Location | | | | | | |
| F value | --- | 3.2 | --- | 6.93 | --- | 3.50 |
| α level | --- | 0.08 | --- | 0.01 | --- | 0.06 |
| Durbin-Watson Test | | | | | | |
| D value | 0.87 | 1.53 | 1.90 | 2.11 | 2.63 | 1.44 |
| Test Result[1] | Not Valid | No | No | No | No | No |
| Percent Outliers | 0 | 4.55 | 0 | 3.42 | 0 | 6.00 |

[1] No = no auto correlation

Yes = auto correlation

Not Valid = no conclusion can be made

Table 6.9 Statistical Characteristics of Patching Prediction Models

| Criterion | Interstate Flexible | Interstate Rigid | Interstate Resurfaced | OSH Flexible | OSH Rigid | OSH Resurfaced |
|---|---|---|---|---|---|---|
| Coefficient Determination ($R^2$) | 0.83 | 0.95 | 0.85 | 0.89 | 0.93 | 0.84 |
| Linearity Test | | | | | | |
| F value | 7.72 | 179.12 | 8.78 | 324.89 | 62.10 | 71.09 |
| α level | 0.06 | 0 | 0.05 | 0 | 0.09 | 0 |
| Significance Test for Coefficients | | | | | | |
| $Log_{10}$ (ΣEAL) | | | | | | |
| F value | 11.46 | 298.61 | 3.56 | 565.15 | 36.98 | 101.35 |
| α level | 0.04 | 0 | 0.08 | 0 | 0.11 | 0 |
| $Log_{10}$ (ΣEAL) * Location | | | | | | |
| F value | --- | 3.83 | --- | 2.70 | --- | 3.27 |
| α level | --- | 0.06 | --- | 0.10 | --- | 0.07 |
| Percent Sealing | | | | | | |
| F value | 6.05 | 87.83 | 4.02 | 212.78 | 3.91 | 34.87 |
| α level | 0.09 | 0 | 0.07 | 0 | 0.08 | 0 |
| Durbin-Watson Test | | | | | | |
| D value | 0.88 | 1.42 | 1.82 | 1.96 | 2.12 | 1.92 |
| Test Result[1] | Not Valid | No | No | No | No | No |
| Percent Outliers | 0 | 0 | 0 | 1.71 | 0 | 8.00 |

[1] No = no auto correlation

Yes = auto correlation exists

Not Valid = no conclusion can be made

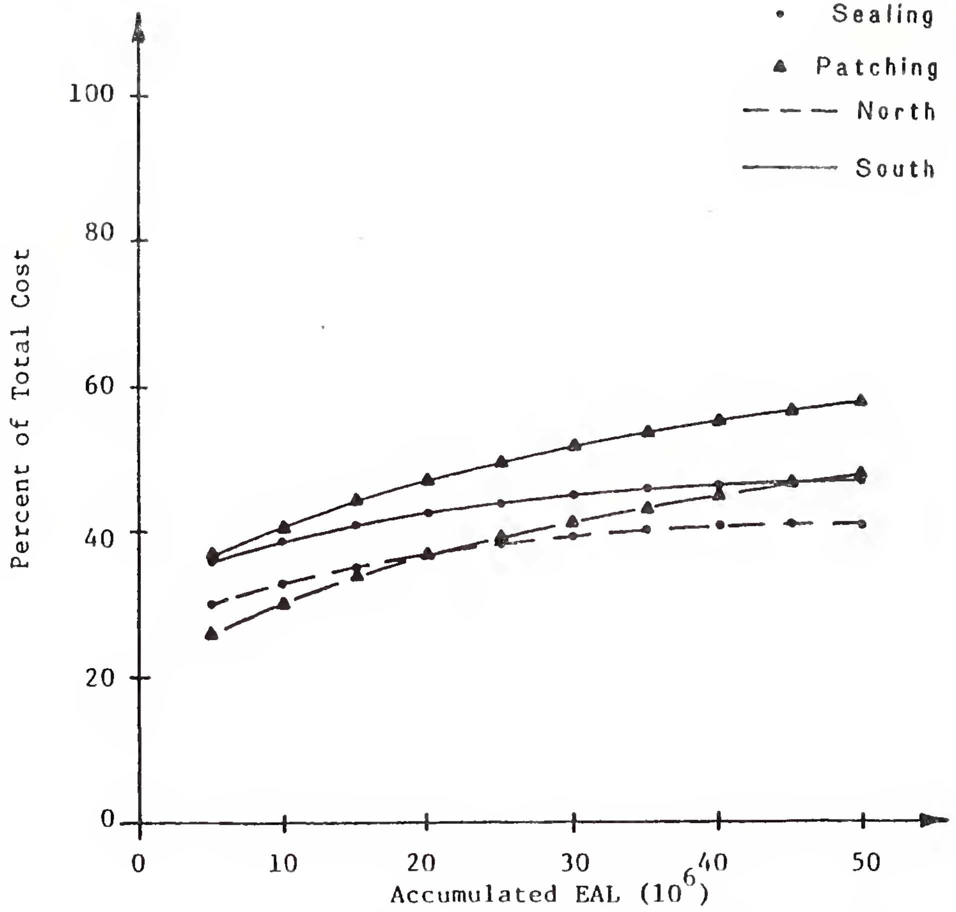

Figure 6.4 Estimated Patching and Sealing Percentages for Interstate Rigid Pavement

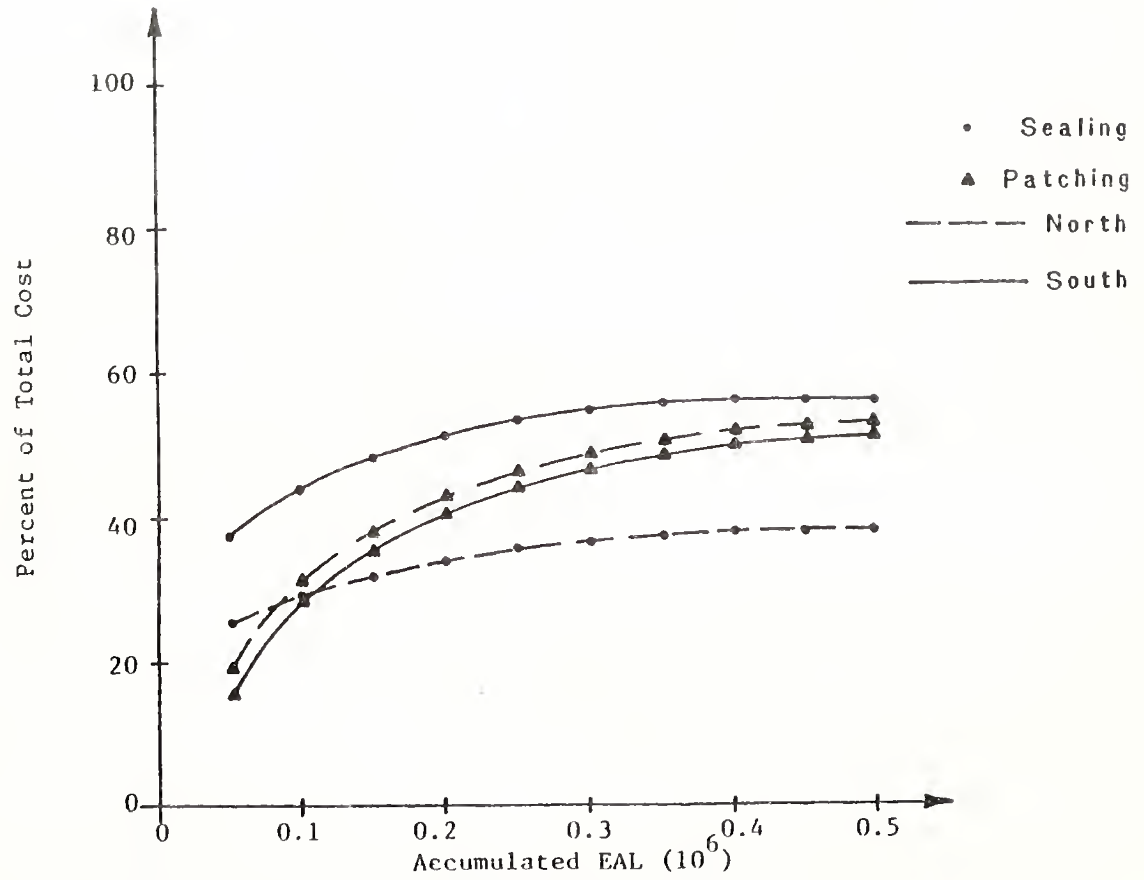

Figure 6.5 Estimated Patching and Sealing Percentages for OSH Flexible Pavement

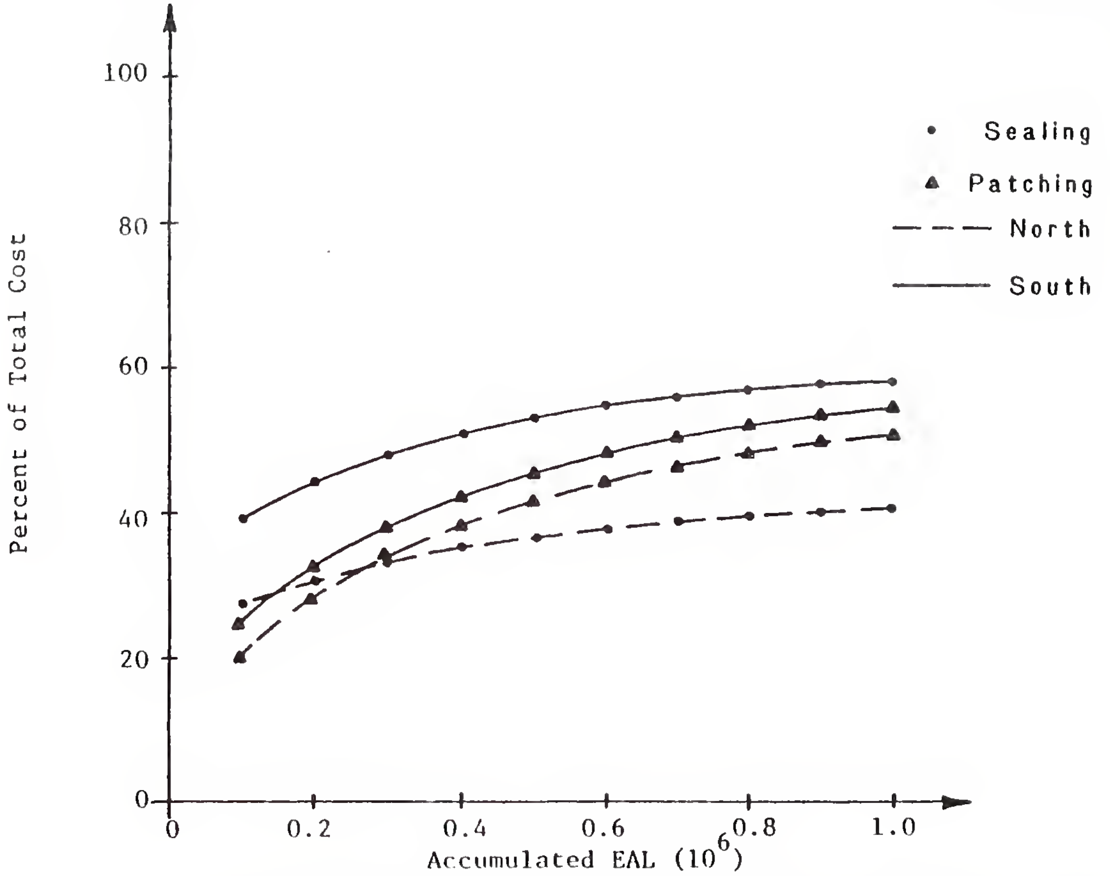

Figure 6.6 Estimated Patching and Sealing Percentages for OSH Resurfaced Pavement

the north for sealing activity. As sealing is a type of preventive maintenance, low level of sealing activity causes a high level of corrective maintenance, patching.

It can be clearly seen from Figures 6.4 to 6.6 that the larger the difference between north and south in sealing cost shares, the smaller the difference between the north and south in patching cost shares. This indicates that there is a trade-off between the level of sealing activity and the level of patching activity. An application of these models in analyzing this tradeoff is discussed in Chapter 7.

## 6.5 Chapter Summary

Two types of regression models were developed. The first was to relate total expenditure to system characteristics and the second was to relate separately sealing and patching expenditures to system characteristics.

In the total expenditure models, it was found that traffic level (accumulated EAL) and location (north or south) were the major factors affecting total expenditure. Several models were developed for various highway class-pavement type combinations.

In the second set, sealing and patching expenditures for different highway class-pavement type combinations were developed. It was found that sealing expenditure was a function of traffic level (accumulated EAL) and location (north or south). On the other hand, patching expenditure was found to be a function of the same factors as in sealing models as well as the sealing expenditure performed before winter during the same year. These models confirmed the negative correlation between patching and sealing activities as explained in Chapter 5.

# CHAPTER 7

# MODEL APPLICATIONS

## 7.1 Introduction

The purpose of this Chapter is to present some of the possible applications of the study results in the area of energy and cost savings in highway pavement routine maintenance activities. In this Chapter two examples are presented. The first considers the energy cost associated with the tradeoff between preventive maintenance (sealing) and corrective maintenance (patching). In the second example, an illustration of pavement maintenance cost savings due to different resurfacing options is discussed.

## 7.2 Assessment of Savings in Fuel Consumption

Energy consumption in highway maintenance activities in terms of direct fuel use by maintenance equipment fleet was discussed and analyzed in detail in an earlier interim report (4). In this section a particular application of this information to estimate energy savings in pavement routine maintenance is presented.

Equations 6.11 to 6.20, discussed in Chapter 6, established that the extent of patching under a given traffic level is a function of the extent of sealing performed in the same fiscal year. The implication of these equations is that a higher level of pre-winter preventive maintenance (sealing) can reduce the extent of post-winter corrective maintenance (patching). At the same time, it was found in this study that energy consumption in terms of gallons per dollar spent in sealing group activities is less than in patching group activities. Consequently, an increased level of sealing activities would not only reduce the need for subsequent patching activities and thus improving the overall pavement serviceability, but it would also cause savings in the direct energy consumption in pavement routine maintenance.

In this example, five scenarios were assumed: increasing sealing level by 5%, 10%, 15%, 20% and 25%. For each of these scenarios, total fuel consumption in terms of gallons/lane-mile/year was calculated and then compared to the current level of energy consumption to estimate the amount of energy saved. With an increase in sealing activities, the fuel consumption for sealing would increase. However, the increase in sealing activity would reduce the level of patching and the corresponding decrease in fuel consumption would more than offset the increase in fuel consumption due to the increased level of sealing. The result would be a net savings in fuel consumption in maintenance equipment fleet. In the following paragraphs a detailed explanation of the procedure to estimate energy savings at different traffic levels is presented.

First, fuel consumption rates in terms of gallons per dollar spent in both patching and sealing groups were developed to avoid the difference in production units of the two groups. Fuel consumption rates developed in the first phase of this study (4) were applied to determine these energy consumption rates. Since the rates given in Reference 4 were on the basis of individual activities, a weighted average rate was estimated for each group. The sealing group includes activities 205, 206 and 207 and patching group includes activities 201, 202, and 203. The computation of weighted average values required information on distribution of both patching and sealing group costs by individual activity. This distribution was obtained separately for each highway category from the results of Chapter 4 (Tables 4.2 to 4.7). For illustration, the case of Interstate flexible pavements can be considered. From Table 4.2, the fractions of total patching group cost in activities 201, 202, and 203 were 0.66, 0.03, and 0.31, respectively. The corresponding energy consumption rates were obtained from Reference 4 and they were .08, 0.132, an 0.11 gallons per dollar, respectively. Thus, the weighted average energy consumption rate in patching group is 0.091 gallons per dollar. Similarly, the average energy consumption rate for sealing group was calculated as 0.07 gallons per dollar. This process was repeated for all highway categories. A summary of the resulting rates is presented in Table 7.1. It can be seen in Table 7.1 that energy consumption levels of the patching group are consistently higher than those of the sealing group.

Energy savings were then calculated for all highway categories under different traffic levels. For illustration, the case of Interstate rigid pavement in the southern zone can be considered. Assuming a traffic level (accumulated EAL) of 20,000,000, the computations are presented below:

a. From Equation 6.4, total pavement maintenance cost = 190.35 \$/lane-mile/year

b. From Equation 6.11, percent allocated to sealing = 42.15%

c. From Equation 6.12, percent allocated to patching = 46.54%

d. Sealing cost = 0.4215 * 190.35 = 80.23 \$/lane-mile/year

e. Patching cost = 0.4654 * 190.35 = 88.58 \$/lane-mile/year

f. From Table 7.1, fuel consumption rates are:

0.094 gallons/\$ of patching, and
0.065 gallons/\$ of sealing.

Table 7.1 Energy Consumption Rates for Sealing and Patching Groups

| Highway Category | Energy Consumption Rates (Gallons/Dollar) | | | |
|---|---|---|---|---|
| | South | | North | |
| | Patching | Sealing | Patching | Sealing |
| Interstate, Flexible | 0.091 | 0.070 | N.A. | N.A. |
| Interstate, Rigid | 0.094 | 0.065 | 0.091 | 0.063 |
| Interstate, Resurfaced | 0.096 | 0.066 | N.A. | N.A. |
| OSH, Flexible | 0.088 | 0.056 | 0.096 | 0.059 |
| OSH, Rigid | 0.092 | 0.065 | N.A. | N.A. |
| OSH, Resurfaced | 0.088 | 0.065 | 0.089 | 0.066 |

Energy consumed in sealing = 80.23 * 0.065 = 5.22 gallons/lane-mile/year

Energy consumed in patching = 88.58 * 0.094 = 8.33 gallons/lane-mile/year

Total energy consumption = 13.55 gallons/lane-mile/year

g. For a 15% increase in sealing activity, the percent of total pavement maintenance cost allocated to sealing is 48.47%

h. From Equation 6.12, the corresponding patching percent is 40.23%

i. Repeating steps (d) through (f) the new total energy consumption is 13.19 gallons/lane-mile/year resulting in a savings of 0.35 gallons/lane-mile/year due to a 15% increase in the current level of sealing.

The above computations were repeated for all highway categories for each of the five levels of sealing activity. The resulting fuel consumption savings for the major three highway categories, Interstate rigid pavement, OSH flexible pavement, and OSH resurfaced pavement, are presented in Figures 7.1, 7.2 and 7.3, respectively.

The information summarized in Figures 7.1 through 7.3 were then utilized to estimate expected total energy savings for the state highway department of Indiana under the five

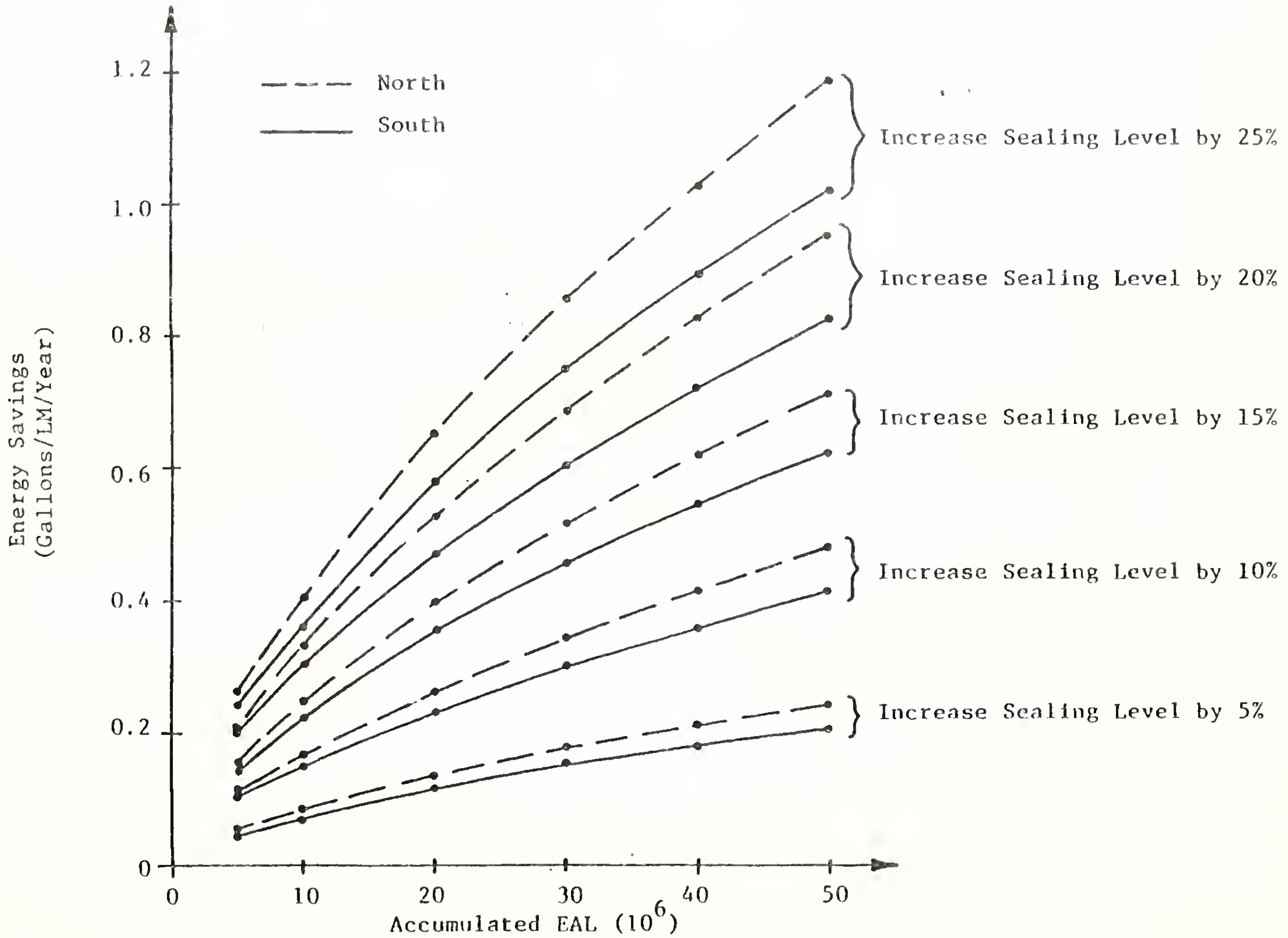

Figure 7.1 Energy Savings Due to Increase in Sealing Level for Interstate Rigid Pavement

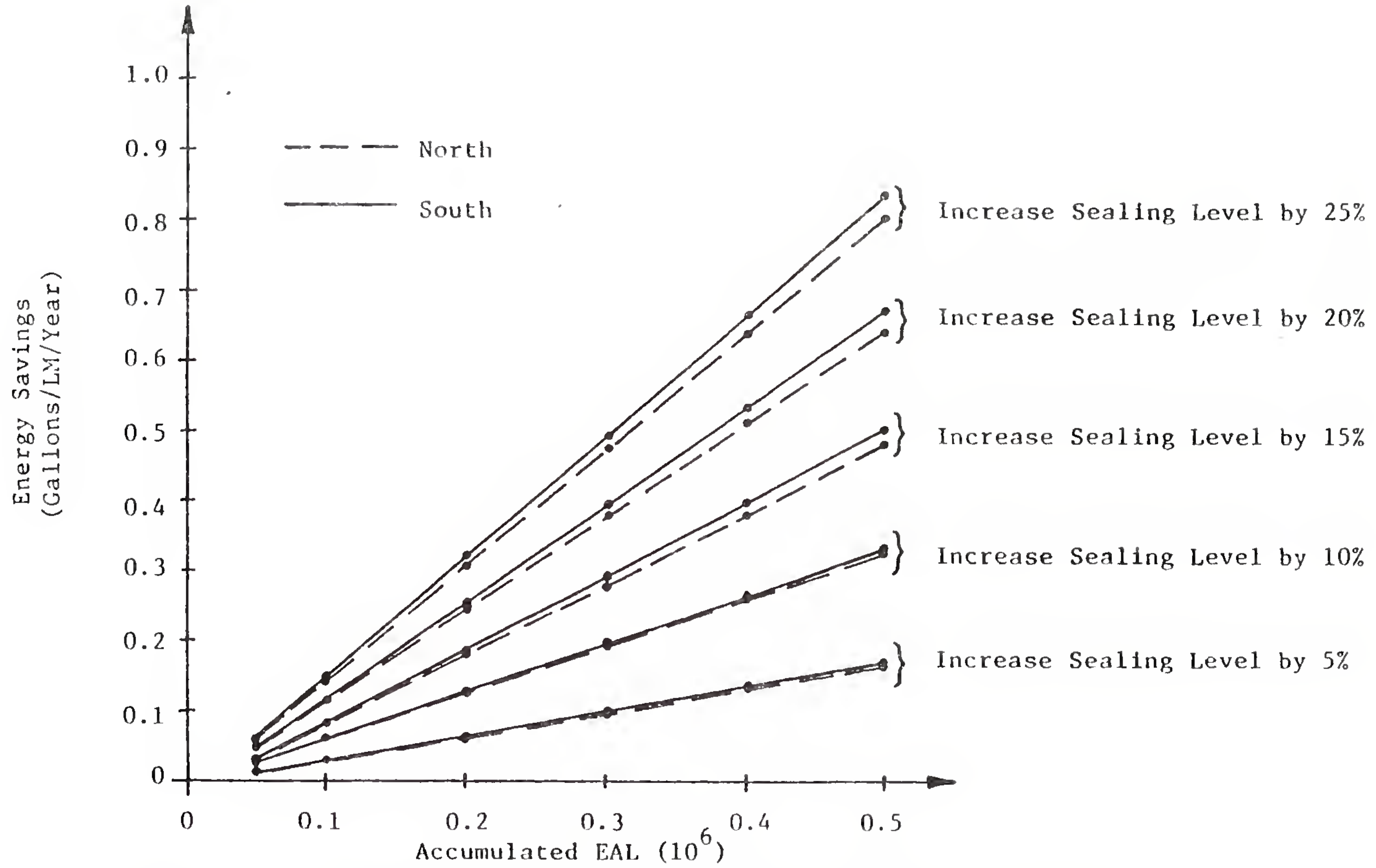

Figure 7.2 Energy Savings Due to Increase in Sealing Level for OSH Flexible Pavement

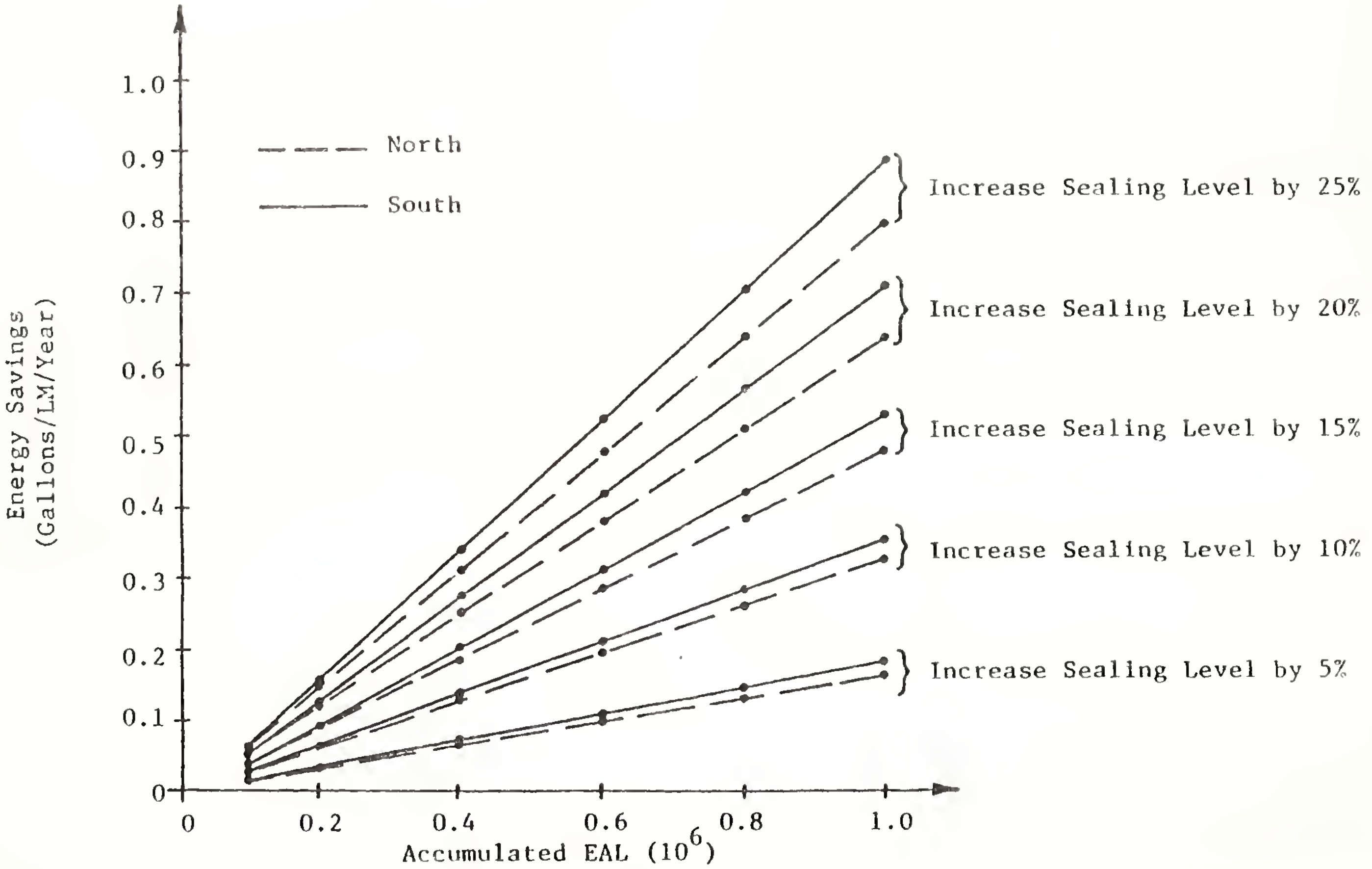

Figure 7.3 Energy Savings Due to Increase in Sealing Level for OSH Resurfaced Pavement

options of increasing sealing level. For example, considering Interstate rigid pavement in the north, with an average traffic level of 25,000,000 accumulated EAL (Table 4.3), a savings of 0.15 gallon/lane-mile/year can be expected with 5% increase in sealing level. This is equivalent to about 0.85% reduction from the current level. Similar computations were done for all other highway categories under the average traffic level and the corresponding percent reductions in energy consumption were calculated. These reduction rates were then weighted by the percent of total lane-miles of each highway category (Table 4.1). The resulting weighted value was taken as the average percent reduction in energy consumption for the entire state highway system. Under 5% increase in sealing level, it was estimated that the average reduction in energy consumption would be about 0.82%. The corresponding reduction rates were 1.64%, 2.5%, 3.3% and 4.1% with an increase in sealing level of 10%, 15%, 20% and 25%, respectively. With an estimated 0.7 million gallons of fuel consumption by equipment fleet in pavement maintenance activities in Indiana state highway system (4). the expected savings in motor fuel consumption can be 5740, 11,480, 17,220, 22,960 and 28,700 gallons under the five levels of increase in sealing activity group, respectively.

Another application of the study results can be made to calculate the energy savings due to a policy that would equate the level of sealing in the north with that of in the south. The fact that sealing level in the north is less than that in the south was discussed in Chapter 6. The computational procedure discussed above was used to calculate the reduction in patching activity in the north due to an increase in sealing activity in the south and then the corresponding energy savings were calculated. It was estimated that this policy would result in an overall savings of 6.0% in maintenance equipment fuel consumption in the northern part. Considering the mileage distribution between the south and north (Table 4.1), the 6% reduction in fuel consumption is equal to about 6,000 gallons of fuel consumption savings.

It should be mentioned here that the energy savings are only the direct benefits of increasing the sealing level. However, there are several indirect benefits associated with an increased program of preventive maintenance of sealing. With an increase in the level of sealing, the required corrective maintenance of patching is reduced indicating a lower level of pavement damages, such as potholes. A lower level of pavement damages would improve traffic safety and provide a higher level of service to highway users with less vehicle operating cost.

## 7.3 Pavement Maintenance Versus Resurfacing

By resurfacing a highway section, an immediate reduction in pavement routine maintenance costs can be expected.

A pavement resurfacing strategy can be based on a comparison of the present worth of yearly reductions in maintenance costs and the capital cost of resurfacing. However, the amount of these reductions and the length of time during which the reductions would continue are questions that should be answered before such an analysis can be undertaken.

Computations were made using the models developed in the present study to provide information that can be used in resurfacing decisions. The computations considered pavement maintenance costs during an analysis period of 20 years under four options of resurfacing: no resurfacing during the 20 year-period (do nothing), resurfacing after 5 years, resurfacing after 10 years, and resurfacing after 15 years. The computations were done for Interstate rigid pavement and OSH flexible pavement. The reason for considering these two highway categories is that these highway sections are the oldest in the State and if any resurfacing decision is to be taken, the probability of chosing a section within these two systems is higher than the other highway categories. In addition, these two categories include the majority of the Interstate mileage and OSH mileage. A set of typical traffic levels was established for each of the two highway categories. Also, to account for possible different rates of traffic growth, two alternate growth rates were considered. Two values of interest rate were used to calculate the present worth value of accumulated maintenance costs. The computational procedure followed the steps discussed below:

a. A highway category is selected with a given pavement type, traffic level, rate of growth, and interest rate.

b. For option 1 with no resurfacing, the appropriate equation is used from Equations 9.11 through 9.20 and the traffic level is updated for each year and the pavement maintenance cost is calculated for each of the 20 years.

c. For options 2, 3, and 4, step (b) is repeated until the resurfacing year, then a new traffic level is started at the beginning of the resurfacing year and appropriate resurfacing equation is used for the rest of the 20 years to calculate the pavement maintenance costs with updated traffic level for each of these years.

d. For each option the present worth of the annual pavement maintenance costs of each of the 20 years is calculated as follows:

$$P = F\left(\frac{1}{(1 + i)^n}\right) \tag{7.1}$$

where,

P = present worth of maintenance cost at the $n^{th}$ year;

F = maintenance cost at $n^{th}$ year;

i = interest rate.

Tables 7.2, 7.3 and 7.4 summarize the results of the computations for Interstate rigid pavement, OSH flexible pavement in the south, and OSH flexible pavement in the north, respectively. It can be seen from the Table 7.2 that for the Interstate system, option 4 with resurfacing after 15 years consistently provides the least accumulated maintenance cost over a 20-year period. Tables 7.3 and 7.4 indicate that for OSH flexible pavement, option 3 with resurfacing in 10 years provides the least accumulated maintenance cost.

Computations can be done to estimate pavement maintenance cost savings as a function of resurfacing timing. Considering the case of Interstate rigid pavement sections under current traffic level of 1.5 million EAL and 4% growth rate, and 4% interest rate, the minimum accumulated routine maintenance cost is 2281 $/lane-mile under option 4. The savings under this option, as compared to option 1, with no resurfacing, is about 250 $/lane-mile. Thus, for a typical Interstate section of 5 miless with 20 lane-mile, a total savings of $5,000 in pavement maintenance can be expected, if resurfacing is done in 15 years.

Table 7.2 Accumulated Pavement Routine Maintenance Costs Under Different Options of Resurfacing for Interstate Rigid Pavement

| Current Traffic Level (ΣEAL/Year) | Accumulated Pavement Routine Maintenance Costs ($/LM) | | | |
|---|---|---|---|---|
| | Option 1[a] | Option 2[b] | Option 3[c] | Option 4[d] |
| | Traffic Growth = 2%/Year, Interest Rate = 4% | | | |
| 250,000 | 897 | 973 | 807 | 783 |
| 500,000 | 1305 | 1457 | 1195 | 1146 |
| 1,000,000 | 1892 | 2182 | 1771 | 1678 |
| 1,500,000 | 2361 | 2763 | 2229 | 2097 |
| | Traffic Growth = 4%/Year, Interest Rate = 4% | | | |
| 250,000 | 962 | 1079 | 894 | 851 |
| 500,000 | 1399 | 1616 | 1326 | 1246 |
| 1,000,000 | 2035 | 2431 | 1966 | 1825 |
| 1,500,000 | 2533 | 3067 | 2476 | 2281 |
| | Traffic Growth = 2%/Year, Interest Rate = 6% | | | |
| 250,000 | 725 | 774 | 653 | 643 |
| 500,000 | 1054 | 1158 | 966 | 940 |
| 1,000,000 | 1532 | 1732 | 1428 | 1375 |
| 1,500,000 | 1907 | 2192 | 1796 | 1717 |
| | Traffic Growth = 4%/Year, Interest Rate = 6% | | | |
| 250,000 | 775 | 855 | 719 | 695 |
| 500,000 | 1126 | 1279 | 1064 | 1016 |
| 1,000,000 | 1638 | 1914 | 1575 | 1487 |
| 1,500,000 | 2039 | 2423 | 1982 | 1858 |

[a] No resurfacing during the 20 years

[b] Resurfacing after 5 years

[c] Resurfacing after 10 years

[d] Resurfacing after 15 years

Table 7.3 Accumulated Pavement Routine Maintenance Costs Under Different Options of Resurfacing for OSH Flexible Pavement (South)

| Current Traffic Level (ΣEAL/Year) | Accumulated Pavement Routine Maintenance Costs ($/LM) | | | |
|---|---|---|---|---|
| | Option 1[a] | Option 2[b] | Option 3[c] | Option 4[d] |
| | Traffic Growth = 2%/Year, Interest Rate = 4% | | | |
| 5,000 | 645 | 432 | 377 | 454 |
| 10,000 | 1268 | 849 | 740 | 892 |
| 15,000 | 1882 | 1260 | 1099 | 1325 |
| 20,000 | 2490 | 1667 | 1545 | 1753 |
| | Traffic Growth = 2%/Year, Interest Rate = 4% | | | |
| 5,000 | 244 | 518 | 445 | 519 |
| 10,000 | 1461 | 1018 | 874 | 1020 |
| 15,000 | 2168 | 1510 | 1298 | 1514 |
| 20,000 | 2869 | 1999 | 1717 | 2004 |
| | Traffic Growth = 4%/Year, Interest Rate = 6% | | | |
| 5,000 | 507 | 337 | 306 | 371 |
| 10,000 | 996 | 663 | 601 | 729 |
| 15,000 | 1479 | 984 | 891 | 1082 |
| 20,000 | 1957 | 1302 | 1180 | 1433 |
| | Traffic Growth = 4%/Year, Interest Rate = 6% | | | |
| 5,000 | 581 | 402 | 357 | 421 |
| 10,000 | 1142 | 790 | 702 | 829 |
| 15,000 | 1695 | 1172 | 1042 | 1230 |
| 20,000 | 2243 | 1551 | 1374 | 1628 |

[a] No resurfacing during the 20 years

[b] Resurfacing after 5 years

[c] Resurfacing after 10 years

[d] Resurfacing after 15 years

Table 7.4 Accumulated Pavement Routine Maintenance Costs Under Different Options of Resurfacing for OSH Flexible Pavement (North)

| | Accumulated Pavement Routine Maintenance Costs ($/LM) | | | |
|---|---|---|---|---|
| Current Traffic Level (ΣEAL/Year) | Option[a] 1 | Option[b] 2 | Option[c] 3 | Option[d] 4 |
| | Traffic Growth = 2%/Year, Interest Rate = 4% | | | |
| 5,000 | 714 | 474 | 411 | 498 |
| 10,000 | 1426 | 946 | 821 | 995 |
| 15,000 | 2137 | 1418 | 1230 | 1491 |
| 20,000 | 2849 | 1890 | 1639 | 1987 |
| | Traffic Growth = 4%/Year, Interest Rate = 4% | | | |
| 5,000 | 826 | 571 | 487 | 571 |
| 10,000 | 1650 | 1141 | 974 | 1141 |
| 15,000 | 2473 | 1710 | 1459 | 1710 |
| 20,000 | 3295 | 2278 | 1944 | 2279 |
| | Traffic Growth = 2%/Year, Interest Rate = 6% | | | |
| 5,000 | 560 | 369 | 333 | 407 |
| 10,000 | 1119 | 738 | 665 | 812 |
| 15,000 | 1677 | 1106 | 997 | 1218 |
| 20,000 | 2235 | 1474 | 1328 | 1623 |
| | Traffic Growth = 4%/Year, Interest Rate = 6% | | | |
| 5,000 | 645 | 442 | 391 | 464 |
| 10,000 | 1288 | 884 | 781 | 926 |
| 15,000 | 1930 | 1325 | 1170 | 1388 |
| 20,000 | 2572 | 1765 | 1559 | 1850 |

[a] No resurfacing during the 20 years

[b] Resurfacing after 5 years

[c] Resurfacing after 10 years

[d] Resurfacing after 15 years

For OSH flexible pavement sections in the northern part with current traffic level of 15,000 EAL, 2% traffic growth and 4% interest rate, the minimum maintenance cost of \$1099/lane-mile is obtained under option 3 with an expected savings of \$557/lane-mile. Thus, for a typical section of 5 miles with 10 lane-miles of OSH, a total savings of \$5,570 can be expected in pavement maintenance, if resurfacing is done in 10 years.

The computational procedure presented here can be used in other applications concerning resurfacing decisions under other conditions after applying the appropriate adjustments for growth rates or traffic levels.

It should be recognized that the analysis is based on aggregated consideration of data and the computations assume pavement sections are in good condition. Moreover, it is further assumed that the sole objective here is the minimization of accumulated routine maintenance costs during the analysis period. The results are therefore applicable only to a macro level analysis and system wide planning of resurfacing. Actual scheduling of resurfacing projects must consider individual pavement sections and those sections with deficient condition rating must be resurfaced sooner then the year indicated for the ideal case. Moreover, resurfacing decision at the level of individual sections should be based on a comparison of resurfacing cost and cumulative routine maintenance cost along with the consideration of appropriate resurfacing design procedures.

## 7.4 Chapter Summary

Two examples of possible applications of the study results in the area of energy and cost savings in pavement routine maintenance were considered. The first application addressed probable savings resulting from increasing the level of sealing activities. It was found that by increasing the sealing activities, the consequent increase in fuel consumption in sealing activities would be less than the fuel saved due to the resulting reduction in the level of patching activities (as presented in Chapter 6). The analysis showed that increasing the sealing level by 5 percent about 6,000 gallons of fuel per year could be saved and an increase of 25 percent would save about 29,000 gallons per year. In addition to these savings, an increased sealing program can also improve the level of service due to an expected reduction in pavement breakups (patching required).

The second example considered an analysis of pavement routine maintenance versus resurfacing. A simple aggregate analysis was performed which presented a methodology to use the results of this study in the area of tradeoff between maintenance and rehabilitation.

## CHAPTER 8

## SUMMARY AND CONCLUSIONS

### 8.1 Scope of the Study

The phase of the study discussed in this interim report focused on pavement maintenance and the objective of this phase was to examine the relationship between level of routine maintenance and pavement characteristics. In this phase a data base was developed which utilized routine maintenance files of the IDOH Division of Maintenance, traffic data and road life information from the IDOH Planning Division, and climatic information from previous studies at Purdue University. A trend analysis of materials and labor use during the last four fiscal years was conducted. The analysis indicated a noticeable shift toward the use of recycled materials and toward a reduced rate of use of bituminous materials.

The state highway system was classified on the basis of system type, Interstate and OSH; pavement type, flexible, rigid and resurfaced; and climatic zone, north and south. For each of the twelve combinations, average total pavement maintenance costs as well as average maintenance rates for individual activities were developed for each of the four fiscal years (1980-83).

### 8.2 Basic Assumptions

Several assumptions were made in the study. These are summarized below.

1. Cost figures used in this study included only out-of-pocket field costs. In other words, these costs did not include administrative costs, equipment depreciation costs, fringe benefits for maintenance workers, and such other items. The reason for excluding these items is that there is no direct relation between these items and the actual maintenance need of pavement sections.

2. In developing traffic data, several assumptions concerning ADT growth rates, percent of trucks, and EAL conversion factors were made, as listed below:

    a. ADT growth rates (between 1978 and 1982) were known only for highway sections in 48 counties out of the 92 counties. To estimate growth rates of the rest of highway sections it was assumed that a known growth rate of a highway within a county (highway section) could be used for the highway section on the same highway in an adjacent county for which growth rate was unknown.

    b. The same approach was applied to estimate percent of trucks on highway sections located in areas without manual vehicle classification stations. It was assumed that the percent of trucks obtained from classification stations could be used for adjacent areas (highway sections) where no classification was done. It should be noted here that this process was done separately for each highway system (Interstate, Primary, and Secondary) and for both rural and urban areas.

c. Similarly, EAL conversion factors (EAL/trucks) as obtained from different truck weigh stations were assumed to be the same on adjacent locations (highway sections).

3. To reflect the major climatic differences in Indiana, the State was divided into two climatic zones. It was assumed that climatic characteristics such as amount of snowfall, rainfall, temperature difference and other characteristics are homogenous or at least not significantly different from location to location within the same climatic zone. This way the difference between routine maintenance expenditure in different locations within a same climatic zone may be attributed to other factors than climatic ones.

4. In developing prediction models (presented in Chapter 6), only homogenous sections were used (highway sections with same pavement type, traffic level, age, and so on, along their entire length). It was then assumed that routine maintenance work loads applied on

such sections were uniformly distributed along their lengths.

## 8.3 Study Results

A detailed correlation analysis was performed to investigate the interrelationships between activity costs and total costs of different years. The analysis showed a high correlation between maintenance costs in a year and the average of the maintenance costs in the previous two or three years. An important result, however, was the high correlation between patching activity in a particular year and sealing activity in the same fiscal year indicating that prediction of patching costs should consider the level of sealing performed at same fiscal year.

The data base along with other results of the study were used to develop prediction models for both the total pavement maintenance cost and the cost for patching and sealing groups. Total cost prediction models indicated that traffic level in terms of accumulated EAL and the interaction effect between traffic level and climatic zone are the most significant factors. It was found that pavement maintenance cost in the northern zone may be as much as 40% more than that in the southern zone. However, this ratio was found to be a function of traffic level; that is, the maintenance cost differential between the north and south increases as the traffic level increases due to the interaction effect of traffic and weather. The prediction models for the sealing group cost showed a strong relationship to traffic level, while patching models indicated that the extent of patching in a year would depend not only on the traffic level, but also on the level of sealing activity undertaken in the same fiscal year.

The use of the models and other study findings was illustrated with two examples. The first example included an estimation of possible savings in fuel consumption through an increased level of sealing activity. The results indicated a possible savings of about 5,500 to 28,000 gallons of fuel per year. The second example considered the effect of different resurfacing timings on the level of routine maintenance costs. The results showed that, on the average, the Interstate sections, assuming they are currently in good condition, will result in minimum cumulative pavement maintenance cost over a 20-year period if resurfaced in 15 years. On the other hand, OSH flexible pavement sections, will result in minimum cumulative pavement maintenance cost if resurfaced in 10 years.

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